1439 Issued July 16, 1912.

U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN 249, PART II.

A. C. TRUE, Director.

THE STORAGE OF WATER FOR IRRIGATION PURPOSES—PART II.

TIMBER DAMS
AND
ROCK-FILL DAMS.

BY

SAMUEL FORTIER,
Chief of Irrigation Investigations,
AND
F. L. BIXBY,
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WASHINGTON:
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A. C. TRUE, Director.
E. W. ALLEN, Assistant Director.

IRRIGATION INVESTIGATIONS.

SAMUEL FORTIER, chief.
R. P. TEELE, assistant chief.[1]

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[1] On furlough, in charge of irrigation census of Bureau of Census.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Office of Experiment Stations,
Washington, D. C., February 26, 1912.

Sir: I have the honor to transmit herewith part 2 of a report on the Storage of Water for Irrigation Purposes, prepared by Samuel Fortier, chief of irrigation investigations, and F. L. Bixby, irrigation engineer. This part of the report deals with the construction of timber and rock-fill dams; part 1 taking up earth-fill and hydraulic-fill dams. There have been inquiries from all sections of the country for information of this nature. In this report suggestions have been made which it is thought will be helpful in leading farmers, cooperative companies, and others to select sites, devise plans, and erect structures such as are commonly used, avoiding some of the mistakes of the past. About 20 structures of a more or less typical nature have been described and illustrated with the same purpose in view.

It is recommended that the report be published as part 2 of Bulletin 249 of this office.

Respectfully,

A. C. True,
Director.

Hon. James Wilson,
Secretary of Agriculture.

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THE STORAGE OF WATER FOR IRRIGATION PURPOSES.—PART II.

TIMBER DAMS.

INTRODUCTION.

Wherever the pioneer has made his way to the frontier, the timber dam in one or more of its many forms has sprung into existence. The purposes for which it is built change with time and place. The old grist and saw mills that dot the landscapes east of the Mississippi River are mute witnesses of the important part timber dams played in the storage and diversion of water for mechanical purposes in the early days of the Republic. The need of stored water for hydraulic mining in the West more than half a century ago aroused new interest in suitable materials for dams, and timber structures became common in the mining districts. The decline in hydraulic mining was followed by the rapid rise and progress of irrigation, so that the same dams which had stored water for the miners were subsequently used by the irrigators. In recent years the development of water power to generate electricity has opened up still another field for such structures.

The timber dam will doubtless continue to be regarded as a suitable and economical structure in all the smaller and less expensive irrigation systems, not only because of its cheapness in first cost and the ease and rapidity with which it can be constructed, but because of its adaptability to a wide range of conditions and locations. In the following pages are given the results of studies of the different types of timber dams, varying from the cheap brush dam to the more costly framed crib dam. Loose rock or rock-fill dams are then taken up. Earth-fill and hydraulic-fill dams are treated in a separate bulletin.[1]

BRUSH DAMS.

From the earliest practice of irrigation in the arid region up to the present time, water has been diverted from the natural stream into the irrigators' ditches by means of brush and rock. In the early

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[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 249, pt. 1.

stages of irrigation development this practice was quite general. The settlers had little money of their own to expend for water supplies, and it was seldom that they could borrow from outsiders. Necessity compelled them, therefore, to resort to makeshifts. Brush was abundant and accessible, and it required but little labor when the spring floods had subsided to build a barrier in the bed of a stream sufficiently high to divert the water into the headgate of a ditch. In building these temporary barriers the pioneers realized that next spring's flood might necessitate repairs or wash them entirely away, but even where heavy repairs or renewals were necessary each season, the builders were amply repaid for the effort put upon them.

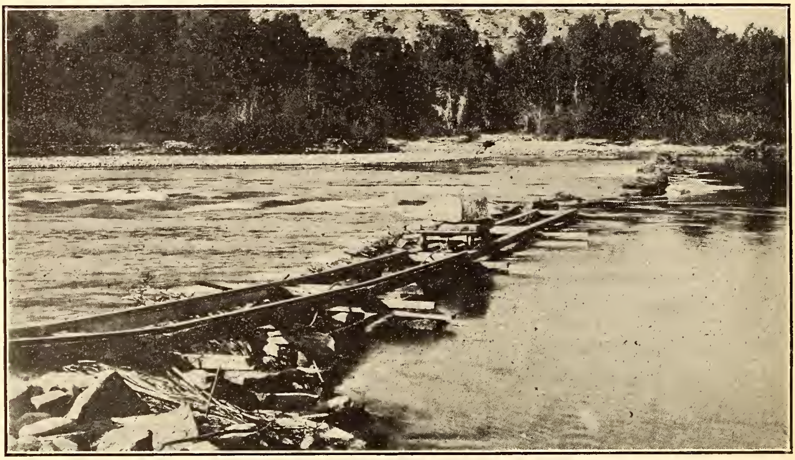


FIG. 1.—Repairing a brush dam on the Yellowstone River.

From the use of a small mat, weighted with rock, placed in creeks and small streams, the practice grew to include the damming up of some fairly large rivers for diversion purposes. A brush dam of the old type is shown in Plate I, figure 1. For 20 years or more this cheap weir and its predecessors, that were carried by floods into Great Salt Lake, served to divert water from Weber River, Utah, into the Davis and Weber Counties Canal.

In the larger dams of this kind the brush is tied into bundles with galvanized-iron wire, these bundles being deposited in layers with the butts downstream and weighted with rock and bowlders. A good example of this construction is shown in Plate I, figure 2. This dam has served for a score or more of years to divert water from the Yellowstone River into the Big Ditch, which irrigates about 25,000 acres of land near Billings, Mont. Figure 1 is a view of the same dam when it was undergoing repairs.

LOG DAMS.

This type of timber dam is practical only where there is an abundance of suitable timber. Its use in this country is associated with the building of the old-time mill ponds which furnished heads to turn water wheels or floated saw logs. In more recent times the same kind of structure has been used extensively in the wooded portions of the West in building dams for the diversion and storage of water for irrigation purposes.

Whether used for diverting or impounding water the crest of the dam should be made so it can be used as a spillway for its entire length. This can be accomplished by the addition of flashboards. The logs are thus kept continuously wet. Without flashboards the upper timbers become dry in periods of low water and wet in periods of high water, and this alternating condition induces early decay. Log dams range from 5 to 15 feet in height and are so built that heavy floods may pass over their crests without injury to the structures. Straight-crested dams with wide aprons are the most common. The aprons should be sufficiently wide to carry the water beyond the point where an eddy is liable to form. A few dams of this type are curved on their upstream face, and others are built with an obtuse angle. The timbers used are generally 10 to 20 inches in diameter at the butt end. A sketch showing the position in which the logs are placed is shown in figure 2. First the largest logs are placed side by side with their smaller ends upstream until the entire bed of the stream is covered. These logs constitute the foundation for the dam proper and also for the apron. Two or more courses laid in a similar position are then added to complete the apron, each course being stepped upstream 10 to 15 feet. In this manner a terraced apron is obtained. The dam proper is then carried up in courses, the logs being laid close together parallel to the stream flow, in such a way that the downstream face formed by the butt ends of the logs will be nearly vertical. Binders 3 or 4 inches in diameter are placed across each course of logs near the downstream slope and secured to the logs by tree nails or spikes, thus adding stiffness to the structure. The spaces between the succeeding courses of logs are filled with saplings, brush, stone, and earth, in order to make the dam as nearly water-tight as possible. To complete, several binders are placed on the top course of logs, and a filling of stone and

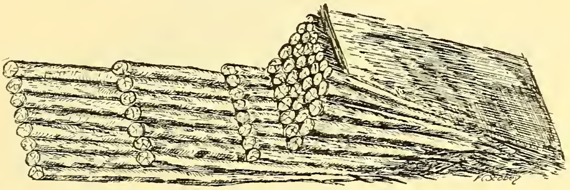


FIG. 2.—Sketch showing manner of placing logs in a typical log dam.

earth is deposited on the upstream side and finished to a uniform slope of about 3 to 1. The earth filling serves to secure watertightness and to prevent to a large extent the passage of water beneath the dam.

PILE DAMS.

The pile dam is a modification of the log dam and is well adapted to mud bottoms, or to any river bed which affords a firm foothold for piling, provided a proper penetration, 8 or 10 feet, can be obtained. Rectangular cribs are first built, extending out from the stream bank on either side. These are inclosed by piling on three sides and filled with rock, their height being 2 or 3 feet above that of the finished dam. Between these cribs three rows of 10 to 16 inch piling are driven, extending across the stream and intersecting the cribs somewhere between the center of their ends and their upstream face. The piles in the two downstream rows are driven close together except where they permit of an occasional longitudinal log passing between them, the purpose of the latter being to tie down the apron. This is shown in figure 3, which is a sketch of a portion of such a dam. The upstream or third row is placed far enough above the two lower ones to permit of binders being placed between it and the two downstream rows of piles across the stream. The individual piles of the upstream row are spaced far enough apart from one another to admit the butt ends of logs between them. Logs 30 or 40 feet long are next laid on the upstream side of the piling, with their small ends upstream and their butts extending between the piling of the upstream row and against the piling of the downstream rows. When a course of these logs has been put in place, a binder is laid across it in the space provided between the rows of piling. Other courses of logs and binders are placed in the same manner, thus giving the logs on the upstream side a slight incline which increases with each succeeding layer placed. The binders, piles, and horizontal logs are all thoroughly driftbolted to each other.

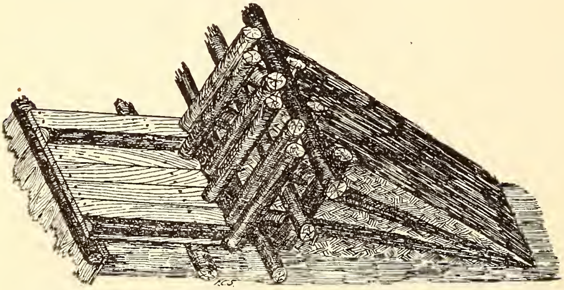


FIG. 3.—Portion of a typical pile dam on a small stream.

The upstream side of the main piling is chinked up with stones that can not wash through, and then a filling of earth and gravel is placed against the dam and around the logs on the upstream side to prevent scouring beneath the piles. The dam is completed by the construction of an apron to prevent the erosive action of the water on the downstream side. This apron extends downstream from the piling a distance at least equal to the height of the dam above the apron floor. Its length is also influenced by the character of the stream bottom. In the construction of this apron a row of sheet piling is first driven to anchor the latter and prevent the water from undercutting it. This row of sheet piling is placed downstream from the main piling at a distance governed by the length of the apron. These sheet piles should extend 6 or 10 feet below the level of the apron floor.

To carry the apron two mud sills of 12 to 14 inch squared logs are placed, one next to the lower row of piles on the downstream side and the other just below the sheet piling, which is securely fastened thereto. These mud sills extend clear across the stream bed. If the ground is uneven it will have to be built up, preferably with rocks and gravel, in order to form a support for the apron sills and floor. The apron floor is formed by cross logs or heavy planking laid upon the mud sills and fastened securely to them and to the piling. A structure of this type can be safely built from 5 to 20 feet in height and forms a satisfactory diversion or impounding dam or both.

LOG CRIB DAMS.

THEIR ORIGIN.

The old log crib dams built in the early days of mining in California are among the best examples of their type in existence. These dams were originally constructed by water companies to conserve the flood waters of the streams on which they were built and to maintain a uniform flow throughout the year for mining operations of various kinds, chiefly placer mining. With the enforcement of the laws instituted by the Débris Commission, placer mining was discontinued to a great extent, and the dams were neglected for a number of years, as the demand for water for other purposes could be easily supplied at that time from the natural stream flows. These dams are being used again, however, for a purpose entirely different from that for which they were built. Irrigation is now making its urgent demands upon water supplies and every means of conserving the spring and winter run-off is being planned and carried to practical completion.

During the years 1852–1856 the Tuolumne Water Co., of California, constructed three large log crib dams and storage reservoirs on the South Fork of the Stanislaus River, the lower one being 34 miles northeast of Sonora, Cal. These reservoirs were for the purpose of storing water through the dry season. The water was let down from one reservoir to another through the regular channel of the river. At Long Camp nearly all the water was diverted into a large ditch and used for hydraulic mining at Columbia, Jamestown, and the surrounding country. In all three dams the original intention was to build them larger, but when they were nearly finished a discovery of gold in another district started every one to the new field, leaving the dams unfinished. They were completed and made fit for service, however, in 1856. Brief descriptions and illustrations of these typical miner's dams follow.

BIG DAM, CAL.

The construction of Big Dam was the most difficult on account of its location. Plate II, figure 1, gives a view of the greater portion of the lake and the dam. A considerable portion of the material was packed in on mules, as access to the site was possible in no other way. Timber was scarce and small and had to be hauled or dragged for a long distance. The trees in the picture are growing in the crevices of the rugged granite slopes and are dwarfed and unfit for use. The dam is 385 feet long and about 40 feet high in the highest place. Originally it was 62 feet in height, but through the decay of the timbers the top 20 feet has disappeared, the last part being removed in the fall of 1907. Plate II, figure 2, shows the débris below the dam and the manner in which the upper slope was strengthened after the upper 20 feet had been cut away. This upper part of the dam was situated where the timbers were subjected to alternate wetting and drying, which in time destroyed the wood fiber. Where the wood has been continuously wet, it is in a fair state of preservation after more than 50 years of service.

The foundation of the dam is laid on the bare granite rock, the bottom timbers being laid lengthwise of the dam and bolted to the rock every 5 feet by steel rods 1 inch in diameter, for which holes had been drilled. The succeeding layers of logs were placed in the regular crib fashion, notched one upon another. They were fastened together by boring holes and driving wooden pins through successive timbers. The manner of laying up the timbers forming the cribwork is shown in figure 5, page 16, a view of the Middle Dam. The upper face of Big Dam was built of 8-inch logs laid on an incline side by side and lengthwise with the flow of the stream, the spaces being chinked with small wedges and earth. Figure 6, page 16, showing an abandoned portion of Middle Dam, illustrates the manner of placing the logs. These logs were notched into the cribwork, had holes bored through them, and were fastened down with wooden pins. This log facing, in the case of the Big Dam, became so rotted that it was replaced in 1899–1900 by two thicknesses of 2 by 12 inch planking. These were lap-jointed, the joints on the top course being covered with 1 by 6 inch battens. The dam conserves in the reservoir a water supply of 1,890 acre-feet, which is equivalent to a continuous flow of about 45 cubic feet per second for a period of three weeks. The reservoir has a watershed of 18 square miles and an average annual precipitation of 10 to 15 feet of snow.

The surplus water from the reservoir flows over a spillway constructed at one end of the dam. This spillway (fig. 4) is 35 feet wide and 3 feet below the crest of the dam. It is equipped with flashboards, so that the water level of the reservoir may be varied at least 2 feet. The posts supporting the flashboards are 6 by 6 inches and spaced 7 feet centers. At times when the river is low the water is drawn from the reservoir by means of a "slum" gate, which is opened and closed by a threaded screw, at the top of which is a capstan nut operated by an iron bar. The gate slides on the upstream slope of the dam. The dam is in a bad state of repair, it being difficult to renew any part, owing to the decayed condition of the wood.

FIG. 4.—Spillway, Big Dam, South Fork Stanislaus River, Cal.

MIDDLE DAM, CAL.

This dam is located 10 miles below Big Dam on the same river. Its structure is the same as Big Dam, being of the continuous crib type. (Fig. 5.) The dam was originally 650 feet long, but about 300 feet was abandoned and in its place a small earth-fill dam was constructed. The portion of the cribwork remaining was retimbered where it had become rotted and two thicknesses of 2 by 12 inch planking were placed on the upper slope. (Pl. III, fig. 1.) The abandoned portion of the dam and the manner in which the logs were placed are shown in figure 6. In the fall of 1907 a new apron was placed in the wasteway, the old apron having rotted out. (Pl. III, fig. 2.) The floor of the apron was built of 4 by 12 inch planks and the uprights are 4 by 6 inch, against which flashboards are placed to vary the water level of the lake. The manner of placing the logs in the cribs and the notching of one on another has been shown in figure 6. The timber used in the construction of this dam was taken from the reservoir site. The site was not thoroughly cleared, however, only the best timber suitable for the construction of the dam being used. This standing timber is rotting at the water's edge and falling into the lake. The current carries the débris down to the dam, forming a big jam on the spillway. A boom of logs was originally placed above the dam to prevent this condition, but on account of

Fig. 5.—Middle Dam, South Fork Stanislaus River, Cal., showing manner of laying logs.

Fig. 6.—Abandoned portion of Middle Dam, illustrating the placing of logs on upstream slope of continuous-crib dams.

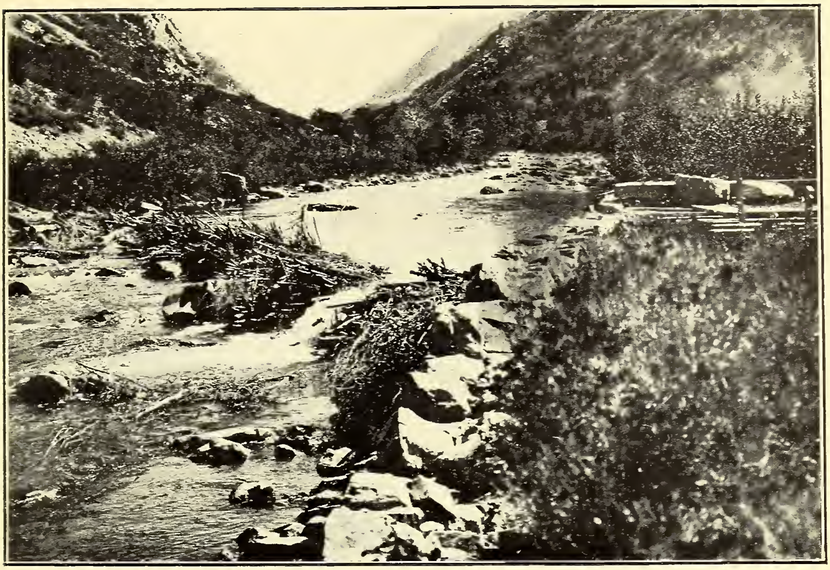


FIG. 1.—BRUSH DAM, WEBER RIVER, UTAH.

FIG. 2.—A BRUSH DAM ON THE YELLOWSTONE RIVER.

FIG. 1.—VIEW OF BIG DAM, SOUTH FORK STANISLAUS RIVER, CAL., SHOWING LAKE AND CHARACTER OF TIMBER ON HILLSIDES.

FIG. 2.—SAME, SHOWING DÉBRIS GATHERED AT FOOT OF DAM.

FIG. 1.—WASTEWAY, MIDDLE DAM, SOUTH FORK STANISLAUS RIVER, CAL.

FIG. 2.—PLANKING ON UPSTREAM FACE OF MIDDLE DAM, SOUTH FORK STANISLAUS RIVER, CAL.

FIG. 1.—LYONS DAM, SOUTH FORK STANISLAUS RIVER, CAL.

FIG. 2.—LYONS DAM, ANOTHER VIEW.

improper connections between the logs the boom broke. Figure 7 shows the result.

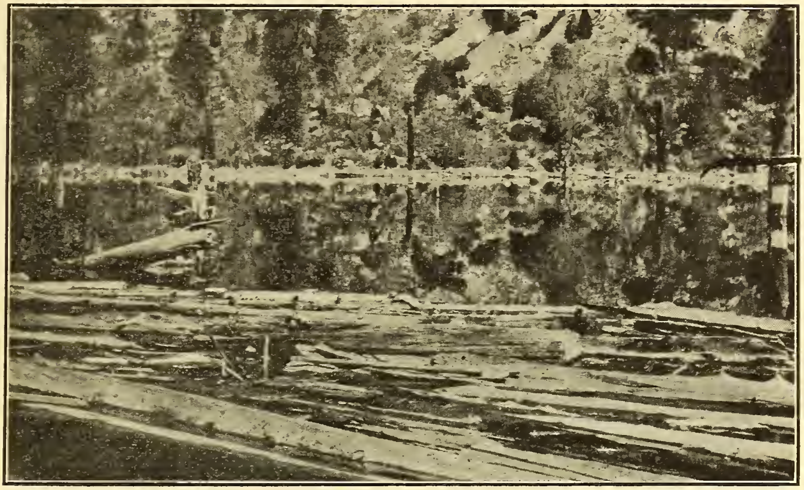


Fig. 7.—Débris gathered at Middle Dam, Tuolumne Water Co., Cal.

LOWER STRAWBERRY DAM, CAL.

This dam is the third in the chain of lakes. It is located about 2 miles above Strawberry Camp and 34 miles from Sonora, Cal.

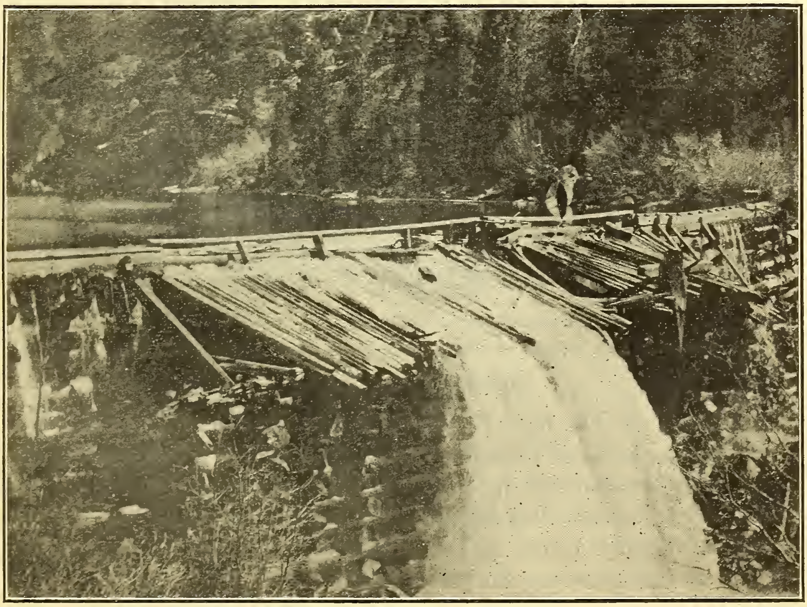
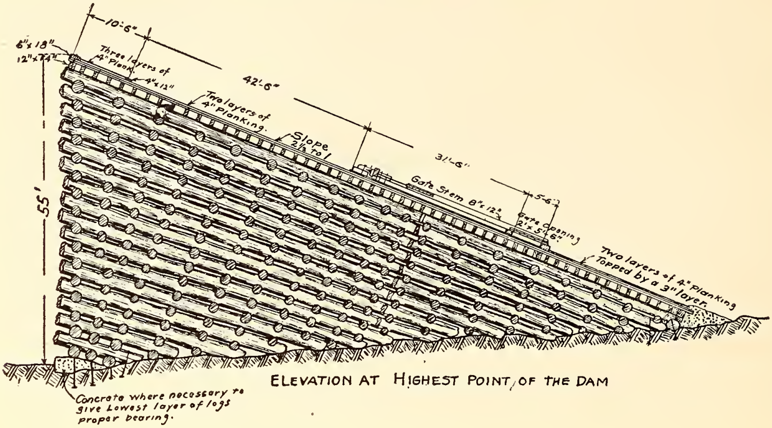
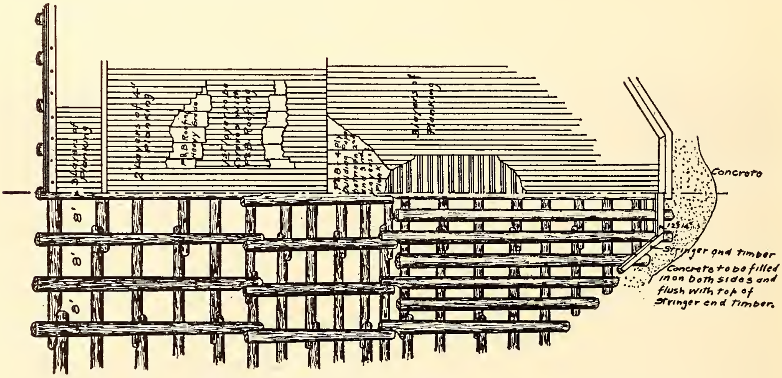


Fig. 8.—Lower Strawberry Dam, South Fork Stanislaus River, Cal.

The dam is 320 feet long and 35 feet high and is a continuous crib constructed of logs notched one on another. (Fig. 8.) A storage reservoir is formed by it which has a capacity of 1,183 acre-feet, which is equivalent to a continuous flow of about 40 cubic feet per second for 15 days. The spillway is 104 feet wide, with a log apron 20 feet wide, built of logs 8 to 10 inches in diameter. The foundation of the dam is similar to that of the two dams previously described, and the cribwork is carried up in the same manner.



ELEVATION AT HIGHEST POINT OF THE DAM



PLAN OF UPPER LAYER OF LOGS.

Fig. 9.—Plan and section of Lyons Dam, South Fork Stanislaus River, Cal.

LYONS DAM, CAL.

This dam (Pl. IV, figs. 1 and 2) is the fourth of the series and completes the chain of reservoirs belonging to the Tuolumne Water Co. It was constructed in 1896–97, after plans and specifications prepared by the consulting engineer. The contract called for $17,000, but with extras the actual cost of building was $21,000. A plan and elevation of this dam are shown in figure 9.

The foundation is located in the stream bed on solid granite rock. The log cribbing was constructed directly on the rock, and where an uneven surface was found, concrete was used to give the lowest logs a proper bearing. At the upper toe of the dam the concrete was filled in on both sides and flush with the top of the stringer end timber. The entire foundation was secured to bedrock with long anchor bolts, well leaded, in holes drilled for the same. The crest of the dam is 148 feet between bulkheads or wings. The total length of dam is 250 feet and its maximum height 55 feet. All logs for the cribwork were cut in the vicinity of the dam site and average 10 to 20 inches in diameter. The upstream face of the dam is built on a $2\frac{1}{2}$ to 1 slope and is covered with two thicknesses of 4 by 12 inch planking over the entire surface with an additional 3 by 12 inch layer over the lower half. The layers of planking are separated by a heavy grade of roofing paper to increase the imperviousness. At both ends of the dam bulkheads consisting of cribbing were built up about 7 feet above the crest of the dam and well anchored to the bedrock. These bulkheads were then faced with planking and filled with loose rock, adding to the stability. (Pl. V, fig. 1.)

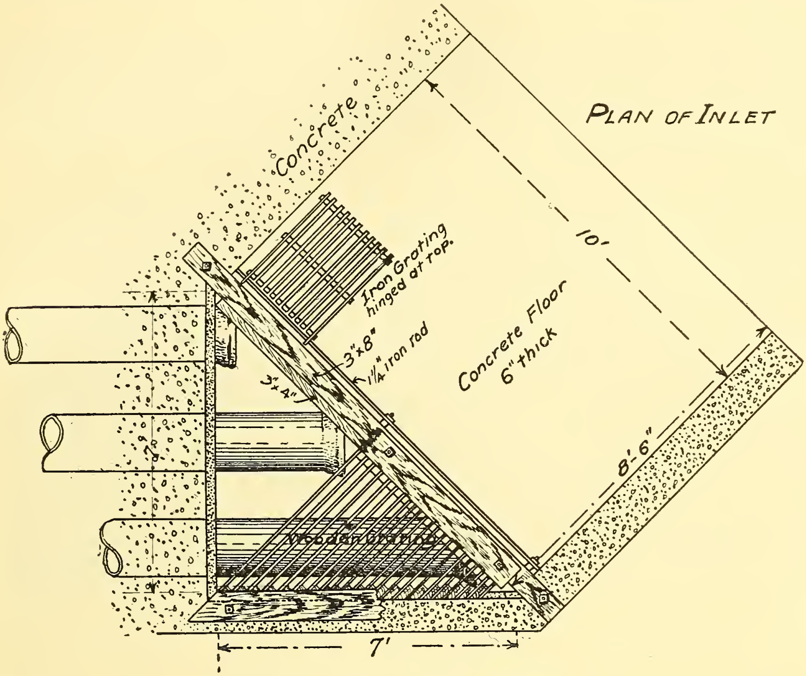


FIG. 10.—Inlet pipes, Lyons Dam.

When the flood season is at its height, the water over the spillway, or that portion of the crest between the two bulkheads, is sufficient to supply a stream of about 60 cubic feet per second. In the drier season of the year water is drawn from the reservoir by means of a tunnel cut through solid rock at one end of the dam. Three 16-inch pipes set in concrete, controlled, respectively, by three 16-inch gate valves, form the outlet to the reservoir. (Fig. 10.) The dam is also provided with two sand gates on its face, with openings 2 feet by 5 feet 6 inches. These are used to sluice out silt from the reservoir. Whether the water flows over the crest of the dam or is drawn out through the tunnel, it passes down the main channel of the river to a point about 1,500 feet below the dam, where it is diverted by a small crib dam into a flume 2 feet deep and 7½ feet wide. (Pl. V, fig. 2.) The average flow of water delivered into this flume is about 45 cubic feet per second, while the maximum is about 55 cubic feet per second. The water is furnished to miners for power purposes and to farmers for the irrigation of fruit trees and garden truck.

BOWMAN DAM, CAL.

This dam is located on the South Fork of the Yuba River, Cal., and is another illustration of the types of dams used in the early days of hydraulic mining. The brief description here given follows that contained in Schuyler's work on reservoirs.[1]

It impounds the drainage from 19 square miles of the high Sierras and has a maximum capacity of 21,070 acre-feet. The dam was built in 1872 to the height of 72 feet. It consists of a continuous timber crib of unhewn cedar and tamarack logs, notched and bolted together and filled with loose rock. The upper and lower slopes were 1 to 1, the upstream slope being faced with a layer of pine planking laid horizontally.

In 1875 the dam was raised to a height of 100 feet by adding an embankment of stone to the lower slope wide enough to carry the entire structure to the desired height, including the cribwork. The outer face of this embankment was made as a hand-laid dry rubble wall in which stones weighing ¾ to 4½ tons each were used. The wall was made 15 by 18 feet thick at the base and 6 to 8 feet at the top. Ribs extending up and down the slope were bolted to the wall on the water face with ¾-inch rods, 5 feet long. A facing of planks was spiked to these ribs. There were three layers of planking, each 3 inches thick, for the bottom 25 feet; two layers, each 3 inches thick, for the next 35 feet; and one layer, 3 inches thick, for the remaining 36 feet.

The dam is 425 feet long on top and has a base width of 180 feet. Like many other of the earlier types of rock-filled crib dams, it was built with an obtuse angle in the center, the apex pointing upstream. Its cost was $151,521.44.

LAKE KEECHELUS DAM, WASH.

[U. S. Reclamation Service.]

This dam is located in the Cascade Mountains in Washington, on the Northern Pacific Railway, about 4 miles north of Stampede Tun-

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[1] J. D. Schuyler. Reservoirs for Irrigation, Water Power, and Domestic Water Supply. New York and London, 1908, 2. ed., p. 65.

nel, the reservoir formed thereby being part of the storage system of the Yakima project of the United States Reclamation Service. This dam is a temporary structure which impounds 12,000 acre-feet of water. It is to be replaced later by a permanent dam which will conserve 98,000 acre-feet. The dam is about 14 feet high in the maximum section and 256 feet long. It was founded on a gravelly bottom cut 2 feet below the original stream bed. All loose material was cleared from the foundation site and leveled sufficiently to give a good bearing to the bottom timbers. The cribwork consisted of logs not less than 10 inches in diameter at the small end and gained at the intersection to a vertical thickness of 8 inches. The logs were notched one on another and piled alternately, crosswise and lengthwise of the dam, in cribs 8 feet square center to center of logs. (Fig. 11.) At each intersection the logs were secured to each other by drift bolts 1 inch in diameter and 16 inches long. The upstream side of the dam is vertical, while the downstream slope is 1½ to 1, breaking into a 6 to 1 slope near the bottom. At the toe of the upstream side a trench 4 feet deep and 2 feet wide was dug the full length of the dam. Sheathing consisting of two courses of 1½ by 12 inch plank was laid with lap joints on the vertical upstream side and extended from the bottom of the trench to the crest of the dam. The sheathing was nailed to the cribbing by wire spikes. The inside course had one 5-inch wire spike and the outside course two 6-inch wire spikes at every intersection with a horizontal log. The trench was then filled with selected material, which was thoroughly puddled,

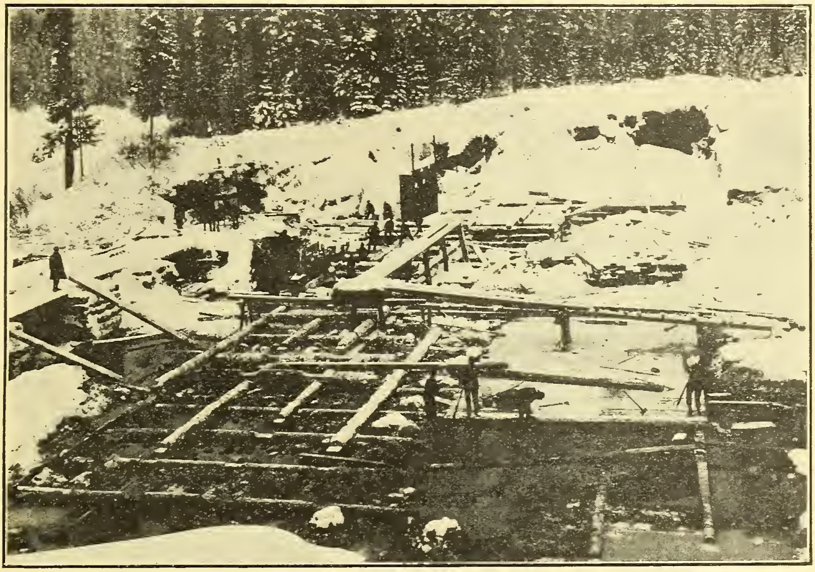

Fig. 11.—Lake Keechelus Dam, Wash. (U. S. Reclamation Service), bottom timbers being placed showing gains cut in splicing logs.

and a clay and gravel embankment with a slope of 2 to 1 was placed on the upstream side of the cribbing. The surface of this embankment was then paved with hand-placed riprap. The cribbing on the downstream side (Pl. VI, fig. 1) was constructed so that the logs were on a 1½ to 1 slope for the upper 12 feet (horizontal measurement), and then a slope of 6 to 1 for the next 12 feet. The latter slope breaks onto the apron, which is 24 feet wide. The apron and spillway were covered with 6-inch hewed timbers with 1½-inch open joints and secured to the logs at every intersection with two ⅝ by 13 inch drift bolts. (Fig. 12.) All holes for drift bolts were bored ⅛ inch smaller than the diameter of the bolt. To bring the channel up flush with the apron a rock fill with a slope of 15 to 1 was placed at the toe of the apron and consisted of hand-placed riprap.

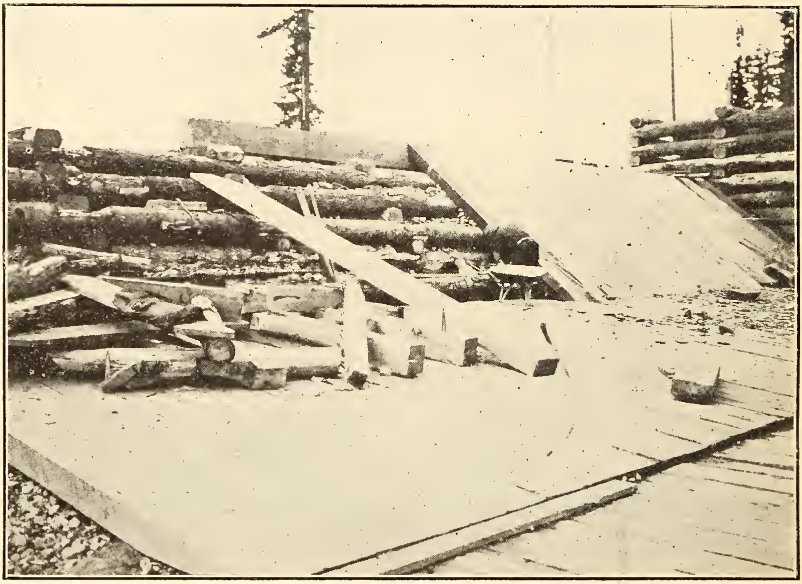

FIG. 12.—Lake Keechelus Dam, apron and spillway under construction, crest log in place and apron completed on east end.

The cribs for the dam proper were filled with gravel and rock. The cribs for the apron were filled entirely with rock, 75 per cent of which was at least one-tenth cubic foot in volume. The outlet consists of three openings through the bulkhead, each 4 by 6 feet, inside measurements. The entrance to the outlet conduit is in excavation with a side slope of 1½ to 1, the bottom and sides being paved with 12 inches of hand-placed riprap. The partition timbers are 12 by 12 inches, hewed, and are secured to each other by ¾ and 20 inch drift bolts at intervals of 5 feet. Sheet piling was driven against the bulkhead around the entrance of the conduit so as to prevent undermining of the bulkhead. This piling was 6 by 12 inches, formed by

2-inch planks, tongue and groove, and had an average penetration in the soil of 9 feet. The completed dam is seen in Plate VI, figure 2, showing the bulkhead with the sheathing partially finished. The location of the outlet is indicated in the picture by two white streaks, caused by the outrushing water. It is also shown in figure 12. The conduits are roofed over by hewed timber laid transversely across partitions and sides, the minimum thickness of these timbers being 8 inches.

The flow of water from the reservoir is controlled by flashboards placed at the upstream end of the outlet conduit. These flashboards are pieces of 4 by 6 inch timber, 6 feet 6 inches long, and have hooks on each end by which they are lifted.

CRIB DAMS OF FRAMED TIMBER.

In the days when lumber was cheap and cement dear this type of dam was used extensively in the West. When built in the rocky channel of a river it served to raise the water above the intake of a diversion canal and at the same time permitted the spring floods to pass over its crest. Structures of this kind have been used for both diverting and impounding water, and their use is pretty certain to continue in all timbered localities remote from transportation facilities.

Apart from stability, water tightness, and general efficiency, the chief feature to consider is durability. No wooden structure will last long if it is alternately wet and dry. Since the lower portion of a dam of this kind is, of necessity, wet most of the time, and the upper portion part of the time, it should be so designed that some water would flow over the crest the year through. If water in a dry season is too valuable to permit of this waste, a set of low flashboards should be built on the crest to keep the dam continuously wet.

The principal features of crib dams of this type are described and illustrated in the examples which follow. As the foundation is an important part of the construction of all types of dams, and as timber dams are no exception to this rule, a few brief descriptions are introduced at the beginning to illustrate the difficulties which are encountered in the building of such foundations in different localities and to suggest the methods employed for overcoming these difficulties. Some of these descriptions are necessarily brief, since there is much similarity in some of the structures, and to avoid repetition only such points are mentioned as will best illustrate the one idea in view.

Much of this matter is equally appropriate to the subject of log-crib dams hitherto discussed. The reader is also referred to the description of the Lyons Dam, page 18, and to that of the Canyon Ferry Dam, page 34, as having special points on the subject of foundations.

Following these brief descriptions which have special reference to foundations, the construction of some typical framed-timber crib dams is given in greater detail.

DIVERSION DAM OF BEAR RIVER CANAL, UTAH.

This structure was built in 1890 at a cost of $45,000 to divert water from Bear River into two canals, having a depth of 10 feet, and a computed carrying capacity of 1,000 cubic feet per second each.

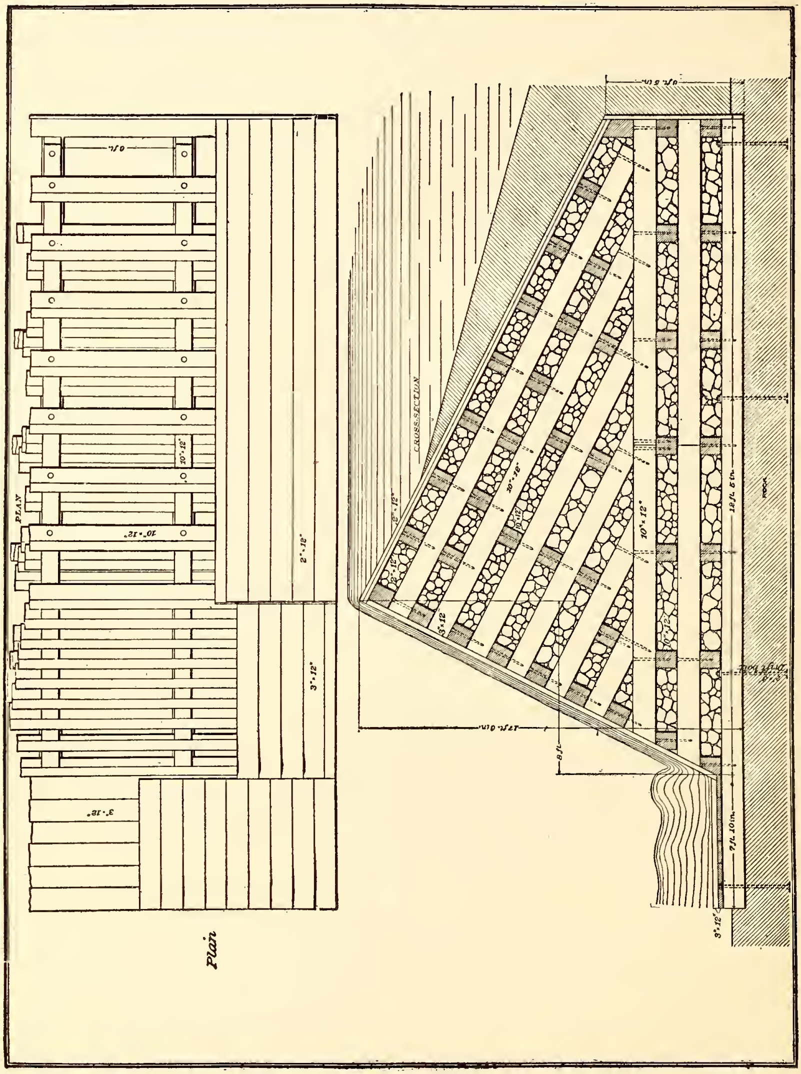

Fig. 13.—Section of dam of Bear River Canal, Utah

Its length along the crest is 370 feet, maximum height 17½ feet, and base width 38 feet. The upstream face has a slope of 2 to 1 and the downstream face ½ to 1. Figure 13 represents a cross section of the dam. In laying the foundation, solid rock was found about two-thirds of the distance across the bed, and the mudsills were securely anchored to bedrock in the manner shown. Over the balance of the bed the mudsills were laid on clay, and upon the completion of the dam and the rise of the water in the forebay, it sprung a leak through the clay underneath the mudsills. This leak was small at first but soon increased and finally the whole river, carrying over 20,000 cubic feet per second, passed beneath the crib. The timber crib, being anchored into the rock, remained intact, and when the spring floods subsided a concrete wall 4 feet thick and 15 feet high was built under the dam where the foundation had washed out. This wall rested upon bedrock and was tied into the upper toe of the dam. The balance of the excavation caused by the escaping water was filled with rock. For the past 20 years it has given entire satisfaction. Figure 13 shows the completed structure.

This partial failure directs special attention to the strength of such structures when properly designed and built, and the need of some kind of a cut-off wall between the foundation and some impervious stratum. Some 60 linear feet of this dam was suspended in the air without foundation for at least six months, with flood water passing underneath and impinging against the upstream face. There is no question that this failure might have been averted by inserting sheet piling or a framed bulkhead at the upper toe of the dam.

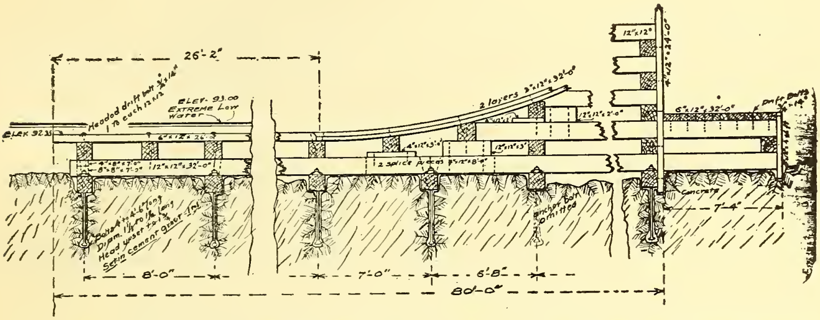

FIG. 14.—Foundation of Barber Lumber Co.'s Dam on Boise River, near Boise, Idaho.

DAM OF BARBER LUMBER CO., IDAHO.

This dam is founded upon a soft sandstone rock in the bed of the Boise River 5 miles above Boise, Idaho, and in order to obtain a good footing for the foundation, 12 by 12 inch sills were placed in trenches cut transversely with the stream, as shown in figure 14. These sills were placed under the upstream edge of the dam proper and under the apron, which is 24 feet wide. The sills at the upper and lower toes of the dam, respectively, and those under the apron were bolted down to bedrock by bolts $1\frac{1}{8}$ to $1\frac{1}{4}$ inches in diameter and 4 to $4\frac{1}{2}$ feet long. Bolts were omitted in those sills immediately under the dam proper. The cribbing above was secured to the foundation timbers by drift bolts which are shown in the figure.

BONANZA DAM, COLO.

This dam is located at Pitkin, near Aspen, Colo., on Castle Creek. In constructing the dam the gravel on the foundation site was removed to a depth of 8 or 9 feet, or until bedrock, a red sandstone, was reached. Two trenches were then cut in the sandstone, transversely with the stream flow, one at the upper toe and one at the lower toe of the dam. A 12 by 15 inch sill was placed in each trench and embedded in concrete, allowing the tops of the sills to come just above the surface of the sandstone. These sills were placed 30 feet 5 inches apart, outside measurement, and formed the upper and lower toes of the dam, respectively. The sills at the upstream toe were bolted to bedrock by 1-inch round anchor bolts, 3 feet long and spaced 6 feet centers. Round, red spruce logs were placed longitudinally with the stream with their ends notched on these sills and a good bearing upon the sandstone bedrock. These logs had been peeled and were 18 inches at the small ends and placed on 30-inch centers. They were secured to the sills by drift bolts $\frac{3}{4}$ inch in diameter and 27 inches long. For the first 4 feet above the level of the foundation the cross timbers forming the upper and lower slopes of the dam were the same size as the sills—12 by 15 inches. At this elevation the timbers on the upstream face were bolted through to bedrock by round anchor bolts 1 inch in diameter, 6 feet long, and spaced 8 feet centers. (Fig. 15.)

LOWER YELLOWSTONE DAM, MONT.

[U. S. Reclamation Service.]

This structure on the Lower Yellowstone project of the United States Reclamation Service is a rock-filled, timber-crib weir on a pile foundation. It has a height of 12 feet and raises the water about 5 feet. The bed of the Yellowstone River at this point consisted of sand and gravel, in places firmly cemented with clay, with occasional detached fragments of ledge rock. In order to obtain a firm footing without excessive excavation, piles were driven averaging 6 feet centers in a line transversely with the dam and 8 feet centers longitudinally with the dam, and were then framed together, as shown in figure 16. These piles extended to an average depth of 20 feet, where a stratum of tough blue clay was encountered, which gave an excellent bearing. At the upper and lower toes of the dam, respectively, a row of sheet piling was driven to an average depth of 15 feet. The piling used was of sufficient length to project well above the water surface and thus form a cofferdam during the construction. The round piles were first driven for the entire length of the dam, and the cofferdam, excavation, and framing of timbers were then done in four sections, the excess length of sheet piling being cut off and the cofferdam wrecked after the completion of each section.

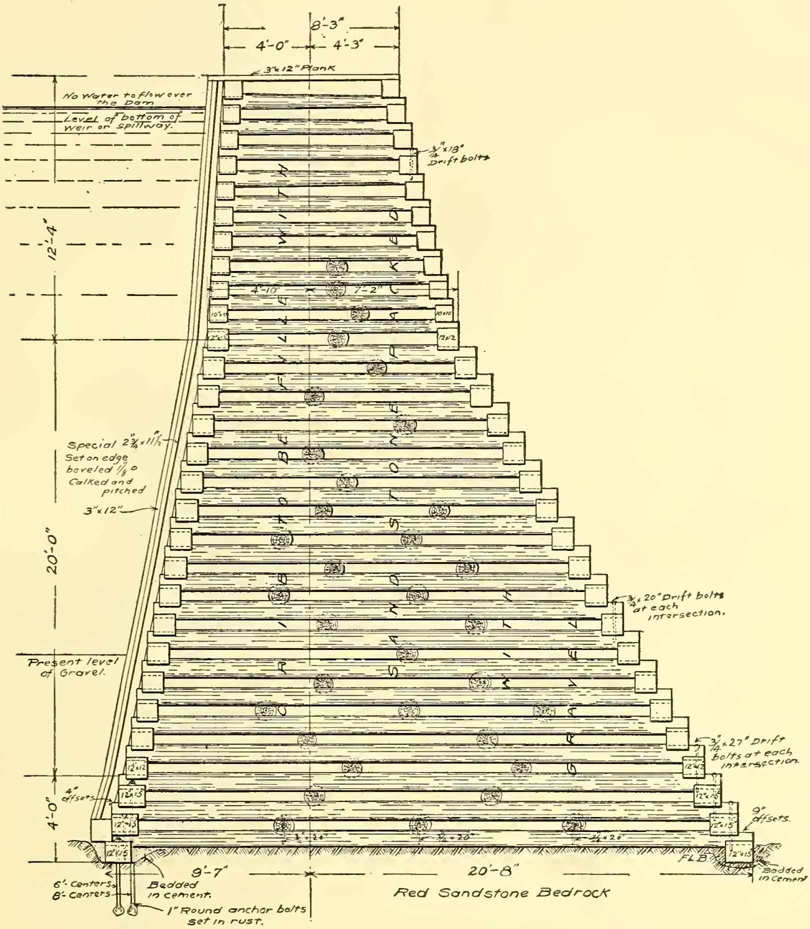

FIG. 15.—Section of Bonanza Dam, Colo.

The original design called for 3-ply sheet piling of the Wakefield type, the specifications being as follows:

Each sheet pile shall be formed of three planks (2 by 12 inch) of uniform width, thickness, and length. All middle planks of these piles shall be dressed on one side to a uniform thickness and the piles shall be formed with tongue and groove and fastened with clinched steel wire spikes. The lower end of each pile shall be chamfered and the piles shall be driven in close contact without shattering. If not in close contact, or if shattered, the sheet piles shall be withdrawn and replaced properly so as to accomplish the required purpose of preventing leakage.

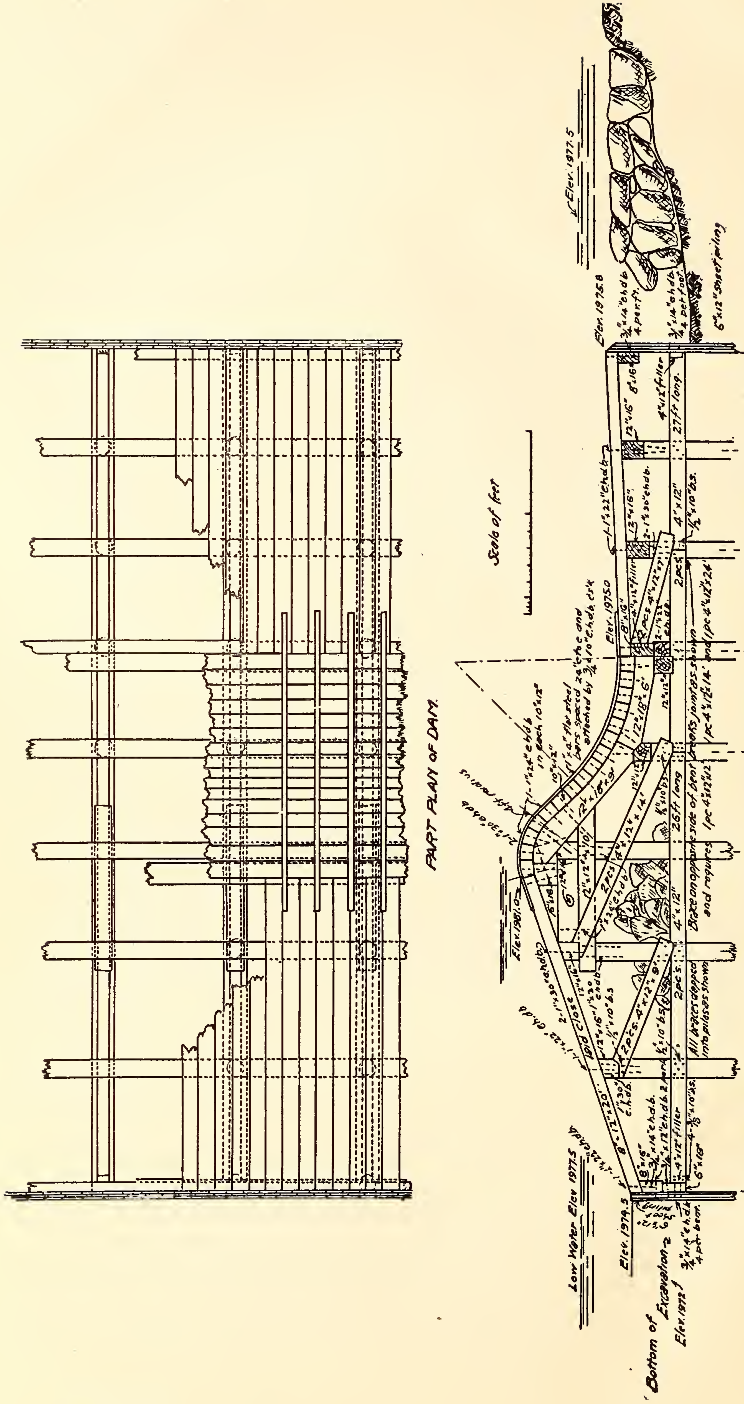

FIG. 16.—Lower Yellowstone Dam (U. S. Reclamation Service).

It was found that this type could not be driven satisfactorily in the material which was encountered, and sheet piles made up of 10 by 10 inch sticks, with tongue and groove of 3 by 4 inch pieces spiked on with $\frac{3}{8}$ by 10 inch bolt spikes, were substituted. These sheet piles proved very satisfactory, both as to driving and as to the exclusion of water, with the exception of two sections on the downstream line with an aggregate length of 236 feet. At these sections the underlying strata could not be penetrated by the wooden sheet piles, and steel sheet piling was required.

MADISON RIVER POWER CO.'S DAM, MONT.

This structure is a rock-filled, timber crib dam on Madison River, 14 miles from Norris, Mont. It has a length of 183 feet, maximum height of 34 feet, and a base width of 92 feet. It is an overflow dam with vertical upstream slope and stepped on the lower slope, each step being 8 feet high and 20 feet wide. In order to form a cut-off in the foundation, a concrete wall was built the full length of the dam. This wall served also as an anchor to the dam. The cribbing was laid up in the usual manner, the course resting on bedrock being secured by anchor bolts.

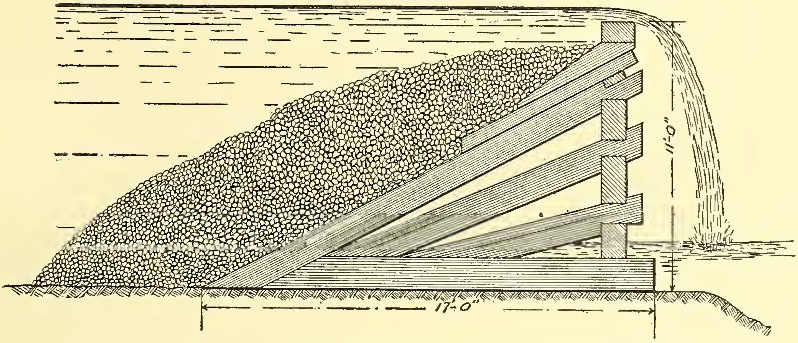

FIG. 17.—Section of timber dam on Schuylkill River, near Plymouth, Pa.

DAM ON SCHUYLKILL RIVER, NEAR PLYMOUTH, PA.

One of the earliest constructions in the United States was the timber crib dam built across Schuylkill River, near Plymouth, Pa., to obtain slack water for navigation. (Fig. 17.) Edward Wegmann in his work on dams gives the following:[1]

> It was constructed on bedrock without the use of a cofferdam. The bottom timbers were 12 by 16 inches and were placed 8 feet apart, parallel with the stream, and secured to the rock bottom by 2-inch oak treenails. The succeeding courses of timber were laid alternately crosswise and lengthwise with the

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[1] Edward Wegmann. Design and Construction of Dams. New York and London, 1911 6. ed., p. 288.

stream. All timbers were securely fastened together with treenails, no iron bolts being used in the structure. The upstream face of the dam was covered with timbers 10 inches thick placed close together. Until this sheathing was laid the water could pass freely between the timbers, as no stone filling was placed in the dam. The covering was laid from both ends of the dam until only 60 feet was left uncovered for the water to pass through. The remaining sheathing was carefully cut, fitted, and put quickly in place by a large force of men before the river could rise so as to interfere with the work. A slope of clay and stone was placed against the upstream face. This dam stood for 39 years, withstanding successfully floods that rose to a height of 11 feet above its crest.

TEBASCO DAM, COLO.

This dam is located in a narrow canyon on Lake Fork of Gunnison River, near Lake City, Colo. It is a bulkhead constructed of timbers 8 by 8 to 12 by 18 inches in size. It has a maximum height of 138 feet, length on top 20 feet, with a minimum width of 38 inches and a maximum width of 74 inches. The face and back of the dam, respectively, are approximately vertical. The dam is constructed as follows: The first 18 feet in elevation was built of 12 by 12 inch timbers, laid in courses, six timbers to each course, making a thickness of 72 inches. From the eighteenth to the twenty-first foot elevation four 12 by 18 inch timbers with the 18-inch edge vertical were used to each course, making a thickness of 48 inches for this part of the dam. From the twenty-first to the fifty-eighth foot elevation the upstream timber of each course was 12 by 12 inches, backed by 36 inches of dimension spruce not less than 8 by 8 inches. From the fifty-eighth foot elevation to the top of the dam, 138 feet, the upstream timber of each course was 12 by 12 inch spruce backed by 24 inches of dimension spruce not less than 8 by 8 inches. The first 18 feet of the dam is braced by 10 by 10 inch braces notched 3 inches into the timbers of the dam and laid one on top of another at an angle of about 45°. This bracing is to prevent the base of the dam sliding. All braces were dry, sound, red spruce and were placed as follows: Four braces below 18-foot level; two braces from 18 to 100 foot level; four braces from 100 to 138 foot level or top of the dam. Two courses of matched sheathing with tar paper between them were placed on the upstream face of the dam in order to make a tight surface. This dam was constructed in 1900 for power and milling purposes.

BIG HOLE RIVER DAM, MONT.

This dam is owned by the Montana Power & Transmission Co. and is located on the Big Hole River about 3 miles from Divide and 21.75 miles from Butte, Mont. The dam was originally built in 1899, afterwards bought by the above company and reconstructed in 1901. It is a rock-filled timber crib dam 512 feet long and 57.5 feet high, with a spillway 189 feet long equipped with flashboards 8 feet 10 inches high. The following description is taken from an article by M. S. Parker, C. E.:[1]

> The bottom of the foundation of the dam is a bed of stiff, yellow clay with bowlders and gravel cemented together. The depth of the foundation below the original surface of the ground varies at the face of the dam from 12 to 25 feet. A concrete core * * * 3 feet 9 inches thick extends from the foundation to about 6 feet above the original surface of the ground. It follows the face planking down and is confined at the back by layers of 2-inch plank spiked to the cribwork. Concrete is also used in front of the face planking for about 10 feet above the foundation. The concrete is composed of 1 part Utah-Portland cement, 2 parts sharp sand, and 5 parts broken stone.
>
> The excavation made in reaching the foundation is back filled with concrete across the river bottom for about 300 feet. The remainder of this excavation outside the planking is filled with a semiclay puddle rammed in layers to the height of the original surface of the ground. Above this clay puddle and concrete filling, on the upstream face of the dam, is an embankment of silt with a slope of 3 to 1. This embankment is about 15 feet high above the concrete filling on the face and 6 feet high above the clay puddle. The dam is constructed of 10 by 12 inch pine and fir timber, laid in continuous cribs, 8 feet between centers. The timbers are laid with the 12-inch side vertical and the cribwork is filled with broken granite. The openings between the timbers are packed by hand with broken granite of irregular surfaces, while the interiors of the cribs are filled in loosely with the same material dumped from cars.
>
> The crest of the dam is 10 feet higher than the spillway. The spillway section consists of a series of steps 10 feet high, the tread or apron of each step being 7 feet wide and consisting of two layers of timber, each 10 inches thick. The high section of the dam is carried up in 10-foot steps with vertical faces, which are filled to a uniform slope from the ground surface. The face of the dam consists of three layers of plank securely spiked to the cribwork. The first layer is of 2-inch plank, over which is a layer of 3-inch plank, breaking joints with the first layer and secured to the crib timbers with 10-inch boat spikes, two spikes to every face timber. Over this is a third layer of 2-inch plank, which also breaks joints. All planking is surfaced on one side and placed vertical on the face of the dam.
>
> The crest of the spillway, like the aprons above described, is composed of two layers of 10-inch lumber with seams calked with oakum. All timbers in the cribwork and aprons are securely bolted with drift bolts ¾ inch square, 20 and 28 inches long. Two 28 and three 20 inch bolts were used in each 16 feet of timber. The face planking is relied upon to prevent leakage, and the granite filling is intended for weight only. Water is taken from the dam through gates into a large wooden flume or forebay 28 feet in depth and 15 feet in width, from which five steel penstocks lead to five 66-inch turbines of special design.
>
> A tunnel is cut through the ledge on the north side to be used for a wasteway to drain down the pond. This wasteway is regulated by a system of gates arranged to control the flow of water to the power house.
>
> The following statement of costs includes the prices paid for the hauling of all material necessary for the work, such as cement, lumber, and iron from the railway station to the dam, a distance of 3 miles.

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[1] Report M. S. Parker, Jour. Assoc. Engin. Socs., 22 (1899), No. 4, pp. 175–195.

Contract prices for different kinds of work, Big Hole River Dam, Mont.

Earth and loose rock excavation below water, per cubic yard	$1.00
Earth and loose rock excavation above water, per cubic yard	.40
Stone filling in crib	.75
Solid rock excavation	1.00
Stone masonry, cement furnished by company, per cubic yard	5.70
Concrete above water, cement furnished by company, per cubic yard	4.05
Concrete below water, cement furnished by company, per cubic yard	5.88
Back filling of earth	.25
Lumber in place (for labor only), per 1,000	10.00

A flood occurred April 16–25, 1898, the water reaching its maximum flood, 3,500 feet per second, on April 18, this being sufficient to cause a flow of several feet above the spillway. A partial failure of the dam occurred at this time, the upper part of the central portion of the dam being pushed downstream, the maximum movement of the crest from original position being 13 feet.

Several causes were attributed for this failure. It was thought by some that the overthrowing pressure of the water, together with the weight of the section of the dam, brought an undue pressure upon the timbers of the cribwork at their intersections. The laying of the dry wall of rocks between the timbers gave an insufficient bearing surface to resist the pressure under the conditions mentioned.

The spillway for this dam, as originally designed by the consulting engineer, was to go through solid rock around one end of the structure, but the members of the company which owned the dam altered this plan. This incident shows the advisability of a State engineer having to pass on all plans for such structures. The partial failure of this dam would probably have been averted if such a regulation had been effective in Montana at this time.

The binding of the timbers together and the thorough settling of the filling of this dam when the water rushed into it probably saved its complete failure. The structure has been largely rebuilt, 30 or 40 feet having been removed from the top and replaced and the balance strengthened.

BUTTE CITY WATER CO.'S DAM, MONTANA.

Two considerations led the engineer in charge of this work to choose the rock-filled crib type of dam. Masonry was too expensive, and there were no suitable materials in that vicinity for building an earthen dam. The dam is 319 feet long on the crest and 42 feet high, including the spillway and the cribwork. It is built of round fir

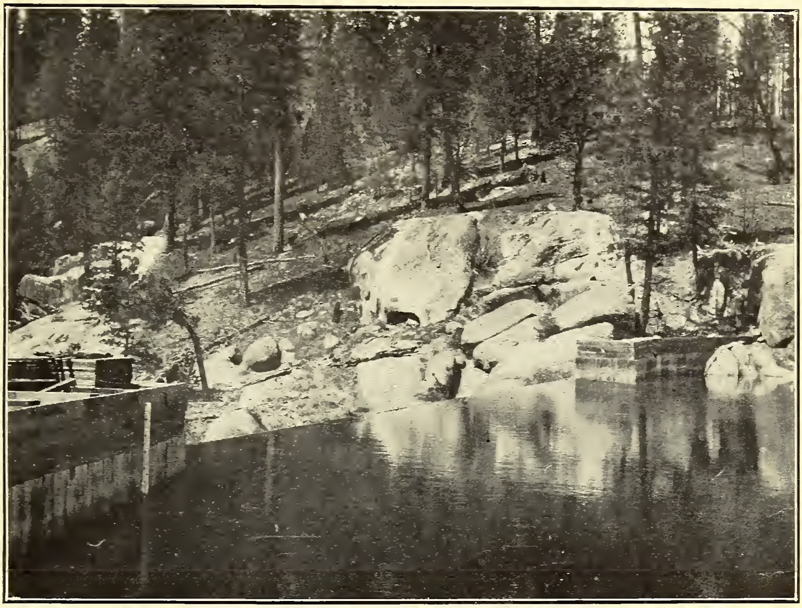

FIG. 1.—BULKHEADS AND CREST OF SPILLWAY, FROM UPSTREAM SIDE, LYONS DAM, CAL.

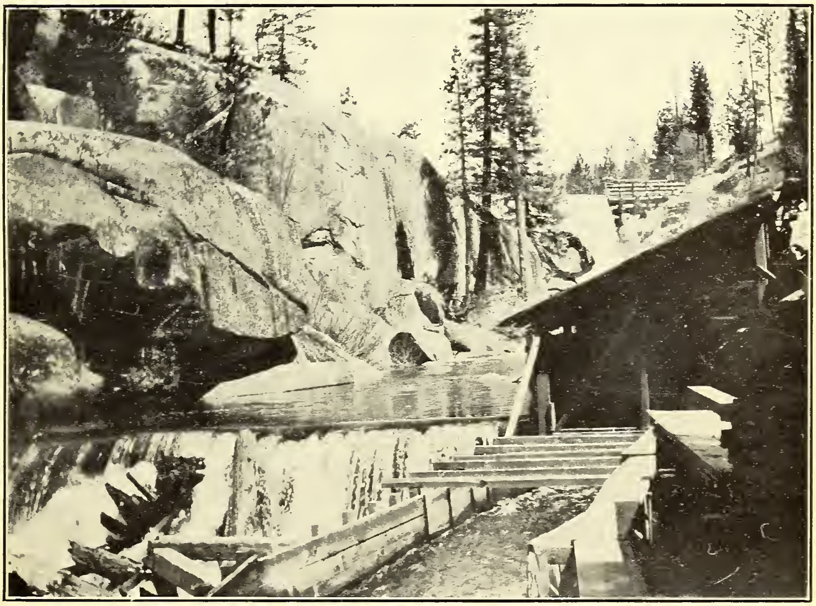

FIG. 2.—DIVERSION DAM AND FLUME BELOW LYONS DAM, SHOWING MAIN DAM IN DISTANCE.

FIG. 1.—LAKE KEECHELUS CRIB DAM DURING CONSTRUCTION, DOWNSTREAM VIEW.

FIG. 2.—THE COMPLETED DAM, LAKE KEECHELUS, WASH., SHOWING SPILLWAY AND BULKHEAD.

logs in cribs 8 feet square. These logs were not less than 7 inches in thickness at the small ends and were all stripped of bark. At all intersections and at every contact a three-fourths inch drift bolt was driven to bring the logs together. Fillers were inserted between the logs, running in the direction of the pressure, as shown in figure 18. These fillers were firmly held in place by drift bolts and were put in to make a greater bearing surface to withstand the pressure and also to prevent the cross logs from rolling when the pressure was received. At each end of the structure the logs were anchored to bedrock when possible.

The upper face of the dam has a slope of 16 feet horizontal to 39 feet vertical; the lower face 24 feet horizontal to 42 feet vertical. The water face is sheathed with 2-inch planking laid double and breaking joints to make it water-tight. This lining extends along the slope of the face to the top of the core wall, thence to bedrock in front of the concrete core wall. It was the intention of the engineer to nail battens over the seams as the water surface lowered in the winter in order to reduce the leakage. The logs forming the water face were hewn to a true surface to receive the sheathing, the lowest one being embedded in the concrete core to form the knuckle where the slope joined the face of the core wall.

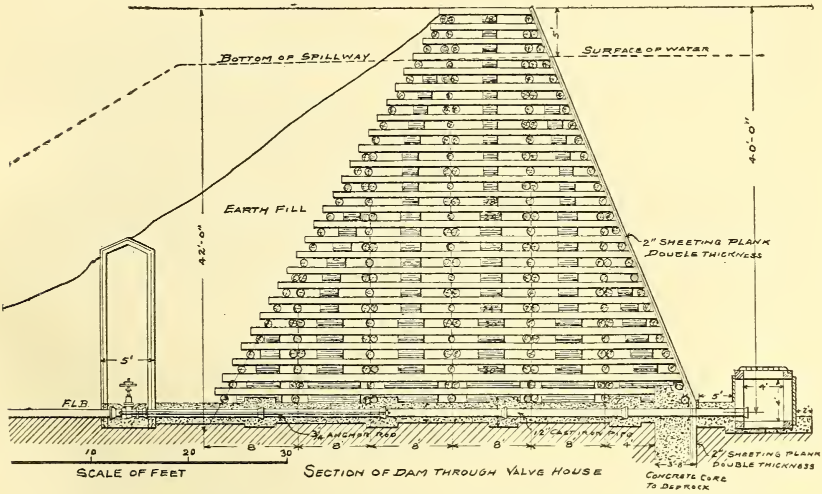

Fig. 18.—Butte City Water Co.'s crib dam, for Reservation No. 2, Basin Creek, Mont.

The cribs were filled with broken rock upon which decomposed granite was flushed so as to thoroughly fill all interstices. Great care was exercised to see that every part of the crib was thoroughly filled. The material was first placed in thin layers and spread by hand. A liberal amount of water was then used to settle it thoroughly and to flush the decomposed granite into the interstices. The concrete core wall was 3 feet 8 inches thick and extended along the inner toe of the cribwork to bedrock. The double 2-inch sheeting on its upper side, previously mentioned, was built to prevent any leakage under the structure. The concrete was made in the proportion of 5 parts broken rock, 3 parts sand, and 1 part cement, and was carefully rammed into place. The wall was carried about 1 foot above the base of the cribwork to support the lower log which formed the knuckle of the sheeting. Where the sloping face of planking joined the vertical sheeting, an additional plank was spiked over the joint horizontally, and all seams were carefully calked with oakum and poured with hot asphalt. A puddle fill of earth and gravel mixed was then made against the dam, extending about 8 feet above the knuckle and 10 feet upstream. The outside seams to the top were then loosely calked with oakum. The calking and puddling about the knuckle were left until the last when most of the settling had taken place. The work on this dam was authorized in the spring of 1898 and the reservoir was completed about July 1 of that year.[1]

CANYON FERRY DAM, MONT.

The Canyon Ferry Dam was built in 1898 across the Missouri River near Helena, Mont., for the Helena Water & Electric Power Co. The plans for this dam were prepared by the consulting engineer of the company. The following data is taken largely from Wegmann's work on the construction of dams.[2]

The dam consists of timber cribs filled with stone. It is 485 feet long and 29 feet high. The cribwork for this dam was built to conform to the bed of the river, which is composed of a compact mixture of gravel and sand and is practically impervious. Both above and below the timber cribbing there is a row of triple lap sheet piling made of 3 by 12-inch planking, stiffly bolted together and driven 12 feet below the level of the bed of the river. Where the material was hard the piling was driven to a satisfactory refusal, or until there was danger of splitting the top of the pile. To further strengthen the dam, a double row of round piling was driven at the toe of the apron, the piles being 3 feet centers. This precaution was to prevent the toe of the apron from being lifted at times of high water.

The timbers of the dam are fastened together with iron drift bolts 20 to 30 inches long. To break the force of the water and prevent

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[1] Data largely from report of Eugene Carroll, Jour. Assoc. Engin. Socs., 22 (1899), No. 4, pp. 196–204.

[2] Edward Wegmann. Design and Construction of Dams. New York and London, 1911, 6. ed., p. 293.

it from scouring out the gravel at the foot of the apron, the downstream face of the dam was formed originally of three steps (fig. 19). First, there was a timber apron 14 feet wide, then two steps with 10 feet rises and treads, then a rise of 7½ feet to the crest. The rises were inclined on a slope of about one-third to 1. The steps were covered with two courses of 3-inch plank lap-jointed. The back of the dam was covered in a similar manner with 2-inch plank. An earthen slope riprapped at the top was placed against the back of the dam, and below the dam large rocks were placed to bring the top flush with the level of the apron. This was extended for a distance of 25 feet and held in place by a double row of round piles on the downstream side. The timber dam is founded on a bed of gravel and granite sand, which is almost impervious to water. Masonry abutments were built on both ends of the crib dam to a height of 12½ feet above its crest or flow line. On the east bank an earthen dam 285 feet long with a masonry core wall and slopes of 2 to 1 and 1½ to 1, respectively, on the upstream and downstream sides, was built to the hillsides. (Pl. VII, fig. 1.) The top of the dam is at the level of the top of the abutments.

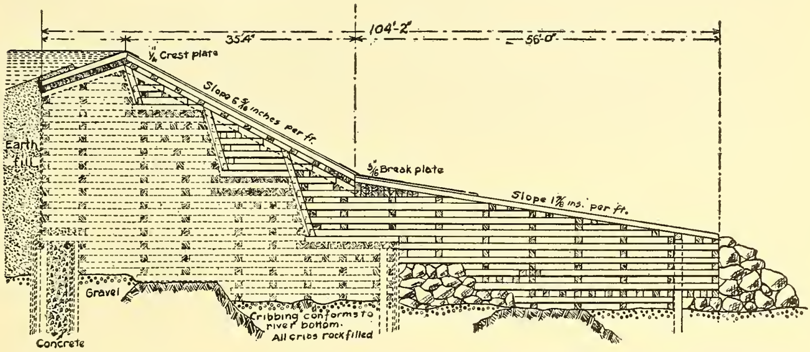

Fig. 19.—Section of Canyon Ferry Dam, Mont., as reconstructed.

Soon after the dam was completed a heavy freshet occurred in which 5 feet of water passed over its crest. With this depth the sheet of water after passing over the first step cleared the other two and struck the apron and protecting riprap with such force as to destroy them both for a large portion of the length of the dam. With the riprap gone, the stream began to scour and undermine the dam, causing it to settle, finally, to 1 foot below its original height and nearly 6 feet downstream out of line. (Pl. VII, fig. 2.) The dam was repaired with new cribbing heavily anchored and tied together. A timber apron 49 feet long was placed on the downstream side of the dam, and two slopes (fig. 20) were substituted for the three steps, the first being 39 feet long and the second 60 feet. About 8,000 yards of rock was used in the reconstruction and 1,500,000 feet of lumber.

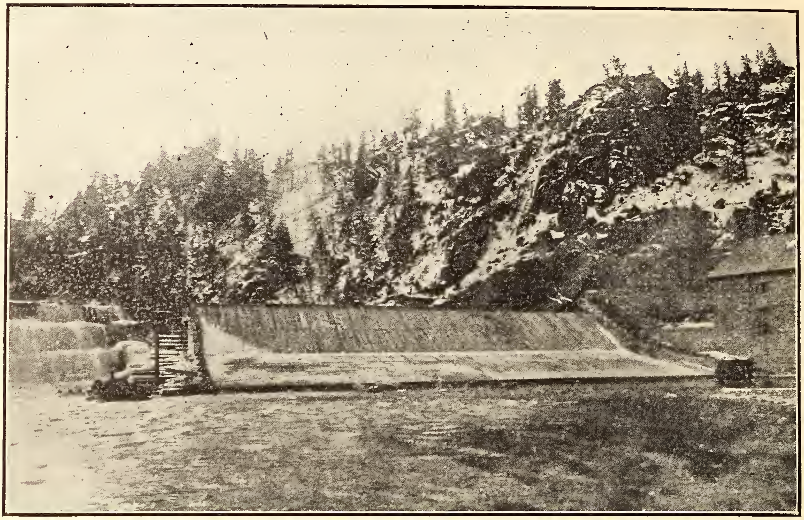

FIG. 20.—Canyon Ferry Dam, showing the reconstructed portion as well as part of the old dam.

During the high water of 1899, 7½ feet of water passed over the reconstructed dam without injury to the structure.

ROCK-FILL DAMS.

TYPES AND DESIGNS OF ROCK-FILL DAMS.

Rock-fill, often called loose rock, dams have been built quite extensively in the West during the past half century. The abundance of rock along the streams, the high price of other building materials, and the lack of good transportation facilities have induced water companies of all kinds to make use of this type of dam. The greater part of such structures consists of loose rock, either dumped into position or placed by derricks. The mass and weight of the rocks provide the necessary stability against water pressure and the resulting tendency of the dam to overturn or slide. Such dams are rendered impervious either by the use of earth, lumber, concrete, or steel. The size of the dam and the ultimate cost of obtaining and placing the materials determine which is preferable in each case.

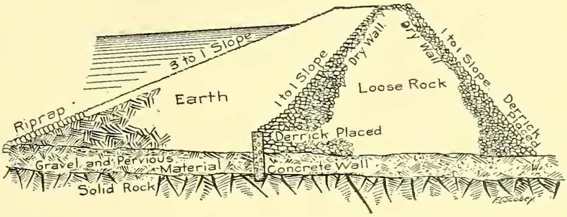

FIG. 21.—Section of typical rock-fill dam.

If suitable rock and earth can be obtained in close proximity to the dam site, a safe and durable structure can be built cheaply in this way.

The site for the foundation should be stripped of all organic matter and should consist of solid rock, hardpan, or other unyielding impervious material. The passage of percolating water along the natural surface is checked by cutting a trench across the foundation somewhere near the inner toe of the dry rubble wall and building therein a concrete wall having its top some distance above the natural surface. A cross section of this type of dam is shown in outline in figure 21. The earth portion of the dam may be built in one of the several ways outlined in Part I of this bulletin;[1] that is, by depositing in layers, moistening, and compacting; by dumping into water; or by sluicing into place. The latter methods are to be preferred where

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[1] U. S. Dept. Agr., Office Expt Stas. Bul. 249, pt. 1.

feasible, as greater water-tightness is assured by their use, since the soft mud borne by the water is deposited in the open spaces of the loose rock, particularly along the upstream face. The earth slope is riprapped as indicated in the same figure.

In districts where lumber is cheap and abundant, rock-fill dams are made reasonably water-tight by placing two thicknesses of plank on the upstream face. The planks are usually spiked to stringers which extend up and down the slope, which in turn are bolted to horizontal timbers set in the rock fill. This practice was common in the time of hydraulic mining in California and is illustrated by figure 22. In rarer cases the planks are spiked to a framework of timber placed vertically near the center of the dam.

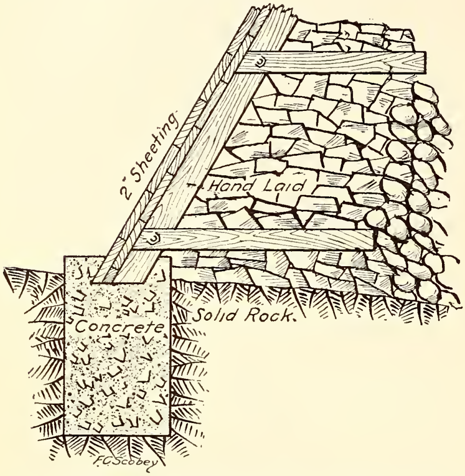

Fig. 22.—Sketch showing method commonly used for facing rock-fill dam with timber.

More or less concrete is now used in the foundation trenches of all rock-fill dams, and frequently the same material is relied upon for the building of an impervious core wall. In the latter case the core wall is usually located near the center of the structure. The chief objections to the use of concrete core walls in rock-fill dams is their tendency to crack, on account of variations in temperature, particularly if the wall is thin. It should be remembered that such walls are more exposed to changes in temperature than are core walls in earthen embankments, and when this material is used for such a purpose provision should be made for expansion and contraction joints. A few dams of the rock-fill type are faced with concrete on the upstream side, but such a facing is liable to be ruptured by the settlement of the loose rock, no matter how carefully it is placed.

The use of steel plates to render rock-fill dams water-tight originated in California and has been used to a limited extent in other parts of the West. When the steel core is thoroughly protected from erosion, punctures, and fractures, this type of dam compares favorably with masonry dams in durability and stability, and also with cheaper types of dams in first cost. The conditions best adapted to this kind of construction are a deep, narrow stream channel in solid rock, where an abundance of rock can be cheaply blasted and thrown into the chasm or readily transported to the site. These conditions are common in the more elevated portions of the arid region, and therefore, since this type of dam is likely to be used extensively in the future, considerable space is here given to a discussion of its principal features.

In designing dams of loose rock, due consideration should be given to the fact that all such structures settle more or less during construction and for some time thereafter. The amount of this settlement depends upon the height of the dam, the character of the rock, and the way it is placed. Under ordinary conditions a dam 100 feet high is likely to settle 2 to 3 feet. Provision must therefore be made to permit the loose rock to consolidate without injury to other parts of the structure. In combination dams of earth and loose rock there is little danger from this cause. The same is true of timber-faced dams of low or medium height, as the loose rock usually has time to settle before the lumber sheeting is put on. On the other hand, in the case of high dams rendered water-tight by either steel or concrete, or a combination of the two, greater care must be exercised. When the steel or other impervious lining is placed on the upstream face great risk is incurred, as the settling of the loose rock is apt to rupture the lining or leave it without adequate support. Danger from this cause can be readily avoided, however, by having the steel or concrete core in a vertical position near the center of the structure.

It is frequently contended that the upstream face of the dam should be made water-tight in order to take advantage of the full weight of the rock. Otherwise, it is claimed, that portion of the structure between the upstream face and the core wall would be submerged and its effective weight decreased to the extent of the weight of water displaced. Notwithstanding this disadvantage, the safety at least of all high dams with steel or concrete core walls requires that the core wall be placed near the center. The factor of safety in such structures is necessarily so large that the loss of weight due to flotation is small in comparison with the weight of the entire structure.

A core wall placed near the center of the dam is not easily reached for repairs or renewals, and for this and other reasons it should be thoroughly protected. A heavy asphalt coating backed by two 12-inch walls of sand concrete was used to protect the steel sheeting in the Lower Otay and other rock-filled dams built in San Diego County, Cal. One of the writers in designing the East Canyon Dam in Morgan County, Utah, substituted a 4-inch layer of asphalt concrete for the 12-inch wall of sand concrete. His reasons for making this change were to secure greater elasticity in the core wall and to more completely protect the steel plates against erosion, punctures, and fractures. The cost was also considerably less. This protected steel core has now been in use for 13 years, and has shown no signs of deterioration.

When conditions are favorable rock-fill dams with steel cores can be built very economically. If possible, the outlet should be made by tunneling through the rock ledge at one end of the site. While this work is in progress a trench may be excavated to bedrock across the canyon and a heavy wall of cement concrete built therein. Having completed the foundation and the outlet, the construction force is ready to fill the entire chasm with loose rock. This often can be done by heavy blasting on the faces of the cliffs above the top of the dam. The top of the concrete wall is protected by timbers. On a favorable site rock can be shot into the stream channel for a few cents a yard. When thrown down by the above method, the fragments vary from small pieces to large masses containing several hundred cubic yards, and, although not consolidated, they give the structure stability and afford an effective barrier to the force of escaping water in case of a break. When loose rock can be so cheaply secured, the question of proper dimensions, slopes, and the like is of minor importance, and it is necessary only to throw down such an excess of rock as will make the structure absolutely safe. This being first done, a channel for inserting the steel core is then excavated directly above the concrete wall through the mass of loose rock. This channel should be of sufficient width to admit the building of a derrick-placed wall on each side of the steel sheeting and its cushions of asphalt concrete. To allow the rock to settle without disturbing the asphalt concrete, wooden forms should be inserted between the rock wall and the concrete, making a division wall between the asphalt concrete and the loose rock fill on either side. By the time the boards decay, the loose rock will have become consolidated, and the dry walls on each side will gradually settle against the asphalt concrete cushion. The sketch shown in figure 23 illustrates the manner of building and protecting the steel plates.

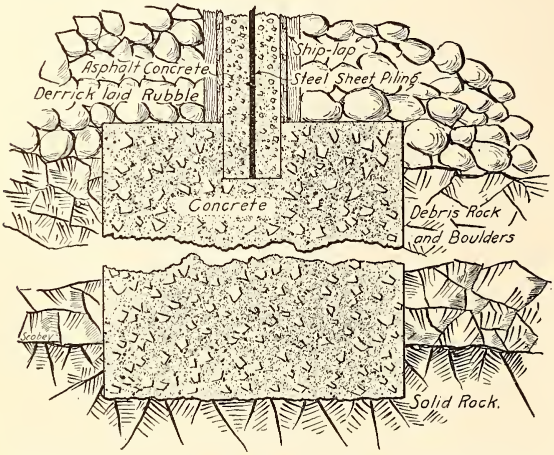

Fig. 23.—Section of concrete base with steel core protected by asphalt concrete encased in wooden forms.

The subjects—outlets, wasteways, concrete core walls, and slope protection for earth embankments—are treated in detail in Part I

FIG. 1.—METHOD OF CONSTRUCTING EARTH FILL AT END OF CRIB DAM, CANYON FERRY DAM, MONT.

FIG. 2.—CANYON FERRY DAM, BEFORE RECONSTRUCTION.

FIG. 1.—EAST CANYON DAM, UTAH, SHOWING TEMPORARY SPILLWAY.

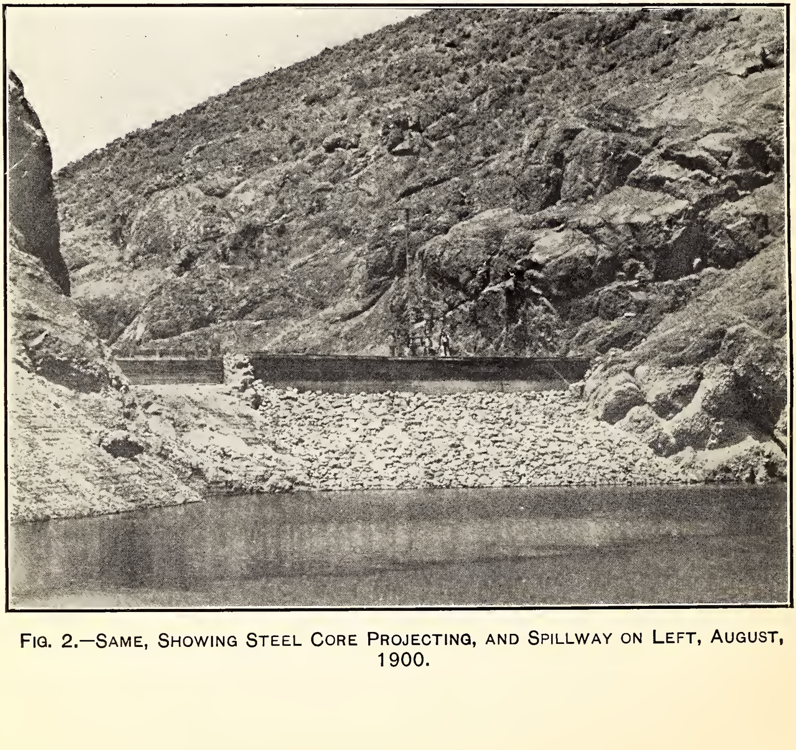

FIG. 2.—SAME, SHOWING STEEL CORE PROJECTING, AND SPILLWAY ON LEFT, AUGUST, 1900.

of this bulletin,[1] and, as many of the points therein discussed are equally applicable to the construction of loose-rock dams, the reader is referred thereto for information along these lines.

A few somewhat typical examples of loose-rock dams are described and illustrated in the following paragraphs:

THE LOWER OTAY DAM, CAL.

The Lower Otay Dam is located about 22 miles southeast of San Diego, Cal. This type of rock-fill dam is the pioneer of the kind, the idea originating with the president of the Southern California Mountain Water Co. It was originally intended to build a rubble masonry dam, and in carrying out this plan an excavation 65 feet wide and 85 feet long was cut from the bed of the stream down to bedrock, a distance of 20 feet. This trench was filled with rubble masonry laid in cement and raised to a height of 28 feet above bedrock, or 8 feet above the stream bed. The loose rock and earth were stripped from the slope at the east end of the dam, but when it came to excavating the earth on the west end the distance to bedrock was so great as to make the building of a masonry dam impracticable. The plan of constructing a masonry dam was therefore abandoned and a loose-rock dam with a steel core adopted.

At the side walls of the canyon a narrow cut or excavation was made through the loose rock to solid rock, and a trench 4 feet in width was extended from this excavation into the bedrock for a distance of 4 feet. This trench was located on the axis of the loose-rock dam, but only 10 feet above the lower line of the masonry wall. On top of the masonry wall at the center line of the trench a T iron was anchored by 1-inch bolts leaded fast in holes drilled in the masonry. The T iron was punched for $\frac{5}{8}$-inch rivets spaced 3 inches center to center to coincide with the punching of the steel plates. These plates were in two sizes, 5 by 17 feet and 8 by 20 feet, and ranged in thickness from 0.259 to 0.34 inch (No. 3 to No. 0 Birmingham gauge). After riveting, the edges of the sheets were split and calked, the sheets having been placed so that the calking could be done on the water side. The steel was then cleaned and a coating of a soft asphaltum (F grade, California-Alcatraz asphaltum) was applied with brushes. To prevent the asphaltum from flowing, strips of burlap were placed on the asphaltum, each strip overlapping the one below about 3 inches. The burlap was brushed on, while the asphaltum was still warm, with a broom used in the same manner as a paper hanger uses a brush in smoothing wall paper. A coat of C-grade asphaltum was then applied on the burlap in the same manner as the first coat, F grade. A coating made in the latter way

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[1] U. S. Dept. Agr., Office Expt. Stas. Bul. 249, pt. 1.

makes a tough, hard covering that will stand on a vertical surface even on a warm day under the direct rays of the sun.

To protect the steel from injury by the rock used in the body of the dam, a narrow wall of concrete consisting of cement and sand was built up on each side of it. Commencing with the first course of steel on top of the masonry dam, this wall was made 8 feet in thickness each side of the core, but narrowed gradually until at a height of 8 feet from the T iron it was 1 foot in thickness on each side. This latter thickness was maintained from this point to the top of the dam. To prevent leakage around the ends of the core the masonry wall was made wider where it joined the bedrock. From about 20 feet from the sides of the canyon, where the narrow trench had been cut into the bedrock, the masonry wall was gradually widened to a width of 20 feet where it joined the rock side walls. The masonry wall was brought up to within 6 inches of the top of the steel before another course of plates was riveted on.

The mortar used was made of best English Portland cement mixed with clean, washed river sand. The proportions used were 1 part cement to 4 parts sand for the end walls and for the narrow wall up to a height of 70 feet, and 1 part cement to 6 parts sand for the balance of the narrow wall. The strength of concrete composed of 1 part cement and 6 parts coarse sand is much below that of ordinary concrete made up of cement, sand, and gravel or broken rock. It is therefore not clear why this mixture was used in the upper portion of the core wall. The mixing of the mortar was done with shovels on platforms located at each end of the dam and near the top. From this platform the mortar was sent down in a chute to whatever height it was being used.

To hold this narrow wall in place until hardened, 2 by 6 inch pieces were set upright, 12 inches from the steel core, as may be seen in figure 24. One-inch boards were nailed to these pieces, leaving a space of 12 inches for the masonry. The uprights were set opposite each other and tied together by nailing on another piece of 2 by 6 inches with its edge resting on top of the steel. On top of this was laid the plank for a runway for the men wheeling mortar from the chute to wherever needed. (Fig. 24.)

The steel sheets were brought as close as possible to the uneven rock of the side walls, without having to cut them, and riveted to bolts leaded into the rock walls. Where not riveted to anchor bolts, short drift bolts of $\frac{5}{8}$-inch iron were put through the rivet holes in the ends of the sheet. These prevented the sheet plate from pulling out of the masonry.

The rock placed in the embankment was a hard porphyry, easily broken, but very hard to drill. The first quarrying was done by drilling holes from 10 to 20 feet in depth for each blast. This method was found to be very expensive and too slow. It was decided to run a drift or tunnel into the hill and make a large blast. The drift was driven for a distance of 50 feet and then branched into a Y. The upper extremities of the Y were enlarged to make powder chambers. The chamber on the right side, or toward the dam, held 2 tons of Judson powder, a low-grade nitroglycerin compound, and the other chamber held 4 tons. After the powder was in place and the two chambers connected with electric wires, the drift was completely blocked with earth and sand. The wires were then connected to an exploding dynamo, which produced the necessary spark, and the blast was set off, throwing down about 75,000 cubic yards of rock. While this rock was being placed in the dam a second blast was being prepared which would furnish enough rock to complete the dam. This second blast consisted of a shaft 115 feet deep, in which two drifts at a depth of 85 feet and two at the bottom were run out at right angles to the shaft. Fifteen tons of powder were used, the greater part being in the bottom chambers. All loose, hanging rock on the face of the quarry was knocked down after each large blast, so the danger of rock rolling down on the men was reduced to a minimum.

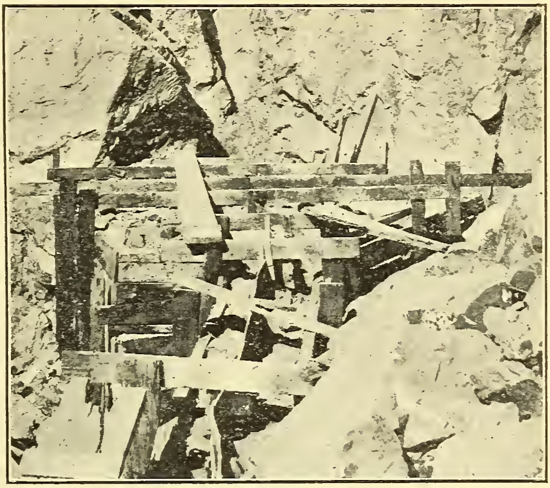

Fig. 24.—Corewall of Lower Otay Dam, Cal., under construction.

The rock was brought from the quarry by means of a Lidgerwood cableway, having a span of 950 feet and capable of handling a safe load of 10 tons. The cable on which the carriage traveled rested on two towers, one 130 feet high and the other 60 feet. This difference in height was due to the difference in elevation where the two towers stood. The cable crossed the dam at an angle of about 60°, the main cable being 60 feet above the crest of the dam. The rock was delivered on the dam by this cableway (fig. 25), and until the dam reached a height of 75 feet it was distributed wherever needed by derricks. The length of the dam at this point being so great that it could not be handled without transferring from one derrick to another, another cableway was erected to take the place of the derricks. This also was a Lidgerwood cableway, but the towers were built on heavily ballasted cars on wheels which could be moved on tracks from a point 15 feet below the core to a point the same distance above, the cable between these towers being parallel to the axis of the dam. This cable was only 30 feet above the dam, thus allowing sufficient room for loads to be carried above it by cableway No. 1. In the quarry a derrick was placed so that a load could be picked up in any part of the quarry and set down directly under the cable.

A loaded skip would be handled in the following manner: First, the derrick would pick up the loaded skip and set it down under cableway No. 1 and take an empty skip back to be reloaded. Cableway No. 1 would then hoist the load and carry it on the dam, where the chains would be unhitched from this and hitched to an empty skip to be taken back to the quarry. Cableway No. 2 would then hoist the load, carry it wherever needed, spill it, and set the skip back under cableway No. 1 before the latter had returned with another load. In this way the cableways and derrick would all be at work without interfering with each other. As high as 225 loads were handled in 10 hours, and the daily average of 200 loads was made for several weeks at a time. This number could have been increased if the quarry had been above the top of the dam. In the present case the level of the bottom of the quarry was but 20 feet above the base of the dam. The time consumed in hoisting and lowering was equal to one-fifth of the time taken to handle a load from the quarry to the dam.

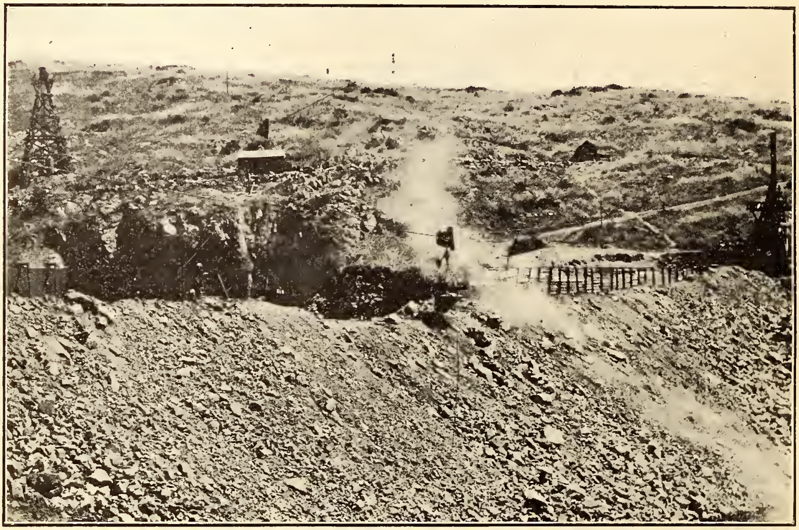

FIG. 25.—Lower Otay Dam—two cableways delivering rock from quarry.

The cables were found to be very convenient in handling other things needed besides rock in the construction of the dam. Wagon roads were built around the towers, and loads of steel or lumber used on the dam could be taken directly from the wagons and carried by the cableways wherever wanted to be used or stored. A covering of dirt sufficient to make a good roadbed was put on top of the dam, and this now serves as a roadway across the canyon.

EAST CANYON DAM, UTAH.

NECESSITY FOR STRUCTURE AND CHOICE OF TYPE.

The type represented by this structure is a modification of that of the Lower Otay Dam. just described. Considerable space is given to this enterprise for the reason that it illustrates what a community of farmers can accomplish under united action. It may likewise serve to encourage other communities that are short of water to join hands in an effort to secure additional supplies by the construction of similar dams. At the time this enterprise was inaugurated the Davis & Weber Counties Canal Co. owned a canal of 100 cubic feet per second capacity, which diverted water from Weber River 10 miles southeast of Ogden, Utah. The tract of land tributary to this canal comprises about 24,000 acres, of which 12,000 is irrigated. This canal company, being one of the latest appropriators of the waters of Weber River, was entitled to a portion of the natural flow only when there was a surplus. Usually about July 1 of each year this company was compelled to close its headgates and keep them closed throughout the remainder of the irrigation period. Not being able to secure water after the spring floods had subsided, the farmers under this system could not raise such crops as vegetables and small fruits, which required water in July, August, and September, but were compelled to resort to grain raising or to one crop of hay, on either of which the profits were small. With water for the entire irrigation season, however, three crops of alfalfa and a large variety of deciduous fruits and vegetables could be grown to perfection.

To provide water for irrigation during the latter part of the season, the company resolved to build a storage reservoir in the Wasatch Mountains. A suitable site was found on East Canyon Creek, a tributary of Weber River, and work was begun in 1897. This creek at the dam site has a flow of about 1,200 cubic feet per second in flood time, but is reduced to about 10 cubic feet per second in September. In selecting the site, advantage was taken of a narrow gorge in the stream channel about 600 feet long. The site of the structure as first located was wholly within the box canyon. This would have permitted of the steel core being vertical throughout its entire length of 100 feet, which was the original plan. In order to lessen the cost of the foundation, however, the site was moved upstream. This necessitated the introduction of an angle in the steel core years later, when the height of the dam was increased. A plan, section, and elevation of the dam and reconstructed portions, as well as some details, are shown in figure 26. The following description of how the original dam and the subsequent extensions were built is taken from the report of the engineers, of whom Samuel Fortier, one of the writers, was consulting engineer, and W. M. Bostaph chief engineer. This report was also printed in an issue of the Engineering Record.[1]

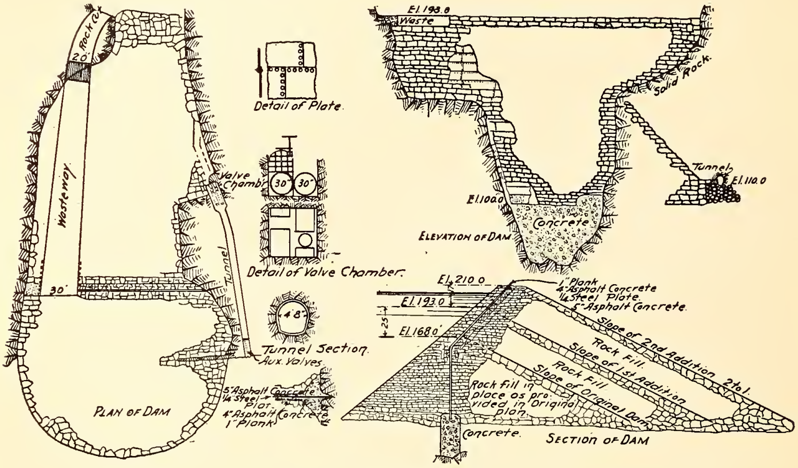

FIG. 26.—Plan, elevation, section, and details of East Canyon Dam, Utah.

FOUNDATION AND CORE WALL.

A temporary dam was built about 1,000 feet above the canyon, and the natural flow of the creek was taken up, carried in canals and flumes, and discharged into the creek below the site. An excavation 15 feet wide was made, extending across the canyon, which at this point was 54 feet between the side walls at the ground level, and solid bedrock was found at a depth of 35 feet below the surface. The engineers decided upon the type of dam known as " rock filled," with a center core wall of steel plate embedded in asphaltum concrete. The first step toward construction was putting in a cement concrete foundation, which was also a cut-off wall. Bedrock was cleared of all loose material; and as it was polished by the action of water in past geologic times, the side walls and bottom were roughened by blasting out several hundred cavities and filling the excavation with concrete composed of 1 part Portland cement, 2½ parts clean, sharp sand, and 5 parts washed gravel. Suitable sand and gravel were found in

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[1] Engin. Rec., 52 (1905), No. 22, pp. 594–596.

abundance within 2,000 feet of the dam site. This part of the work was completed in March, 1898, and in August following a contract was let to build the dam. This as originally built extended to a height of 68 feet above the original bed of the creek and 58 feet above the bottom of the outlet tunnel. The steel-plate center wall was composed of plates 5 by 20 feet, riveted together with $\frac{5}{8}$-inch rivets on $2\frac{1}{2}$-inch pitch. There were three tiers of sheets, the bottom tier 20 feet in height and $\frac{3}{8}$ inch thick; the middle one 20 feet in height and $\frac{5}{16}$ inch thick; the top one 28 feet in height and $\frac{1}{4}$ inch thick. The seams were riveted and calked water-tight, and the whole was covered with two coats of refined asphaltum. The foot of the bottom tier was riveted between two angle bars 3 by $4\frac{1}{2}$ by $\frac{5}{16}$ inch and rested on the concrete foundation. The steel core wall extended across the canyon and $1\frac{1}{2}$ feet into a trench blasted into the side walls.

The steel center was embedded between two walls of asphaltum concrete, each 4 inches thick. These walls were increased in thickness at the ends of the steel-plate core wall to 4 feet to make a more secure joint with the side walls of the canyon. This concrete was composed of 30 per cent sand and 70 per cent gravel, mixed with refined asphaltum, allowing 9 pounds of asphaltum per cubic foot of mixed sand and gravel. The whole was mixed while heated to a temperature of 250° F. and deposited and rammed into place while hot. The bottom of the steel wall for a distance of 5 feet up the plate was embedded in cement concrete.

EXCAVATING AND PLACING THE ROCK.

A dry-rock wall was built up on either side of the core, the stones being carefully laid and bonded, with all the spaces filled with broken rock. Each wall was 20 feet in thickness at the bottom and 10 feet at the top. The inner faces of these walls were about $8\frac{1}{2}$ inches apart. On the upstream side of the dam a face wall 5 feet in thickness was laid on a slope of 1 to 1. On the downstream side the face wall was the same thickness and laid on a slope of 2 to 1. The portion of the dam between these walls and the walls next to the core was filled with rock dumped in, with all the spaces carefully filled. The rock for all this work was procured by blasting it from the sides of the cliffs on either side of the canyon. This fell in large masses, many containing from 500 to 1,000 cubic yards each. The blasting was done before the core was built up. The rock that fell on and near the concrete foundation was removed and the latter cleaned of all materials. The steel-plate wall was then set in position and the cement concrete around the bottom and the asphaltum concrete deposited and rammed. The walls were built of large stones hoisted into position with derricks.

OUTLET TUNNEL AND VALVES.

The upper portal of the outlet tunnel is at a point 70 feet to the right of the north end of the dam. This tunnel, originally, was 190 feet long and excavated through the solid rock side wall of the canyon so as to carry the discharge below the downstream toe of the dam. The tunnel was built horseshoe-shaped, 6 feet in height and 5 feet 5 inches in width. Two main valves were located at the upper portal of the tunnel, each attached to a 30-inch steel pipe extending 12 feet into the tunnel and embedded in a bulkhead of cement concrete which securely closed the tunnel against the passage of water, except through the valves and pipes. Stems, attached to the valves, reached to an operating platform attached to the side of the cliff above the surface of the reservoir. Two auxiliary valves, in all respects like the main valves, were placed at a point in the tunnel 130 feet from the upper portal. A shaft 8 feet square was sunk from the cliff above, intersecting the tunnel at this point and extending to its floor. These auxiliary valves were the same size as the main valves. Each was connected to two 30-inch cast-iron pipes, which extended a short distance into the tunnel either way, and were likewise embedded in solid bulkheads of concrete. Valve stems reached to an operating platform built on top of the valve chamber. All the large valves had handwheels at the tops of the stems. To equalize the pressure on both sides of the main valves a 6-inch pipe controlled by a separate valve admitted water from the reservoir into the upper portion of the tunnel. A similar pipe and valve were used in connection with the auxiliary gates to drain the water from the upper portion of the tunnel when it was desired to remove all pressure from the auxiliary gates. By this means the operation of either set of gates was facilitated.

WASTEWAY.

Since it was intended to increase the height of the dam whenever means were available, a temporary wooden wasteway was built to by-pass the flood flow of the stream when the reservoir was full. A wasteway 30 feet wide and 6½ feet deep is provided, being located on the south end of the dam. A flume constructed of lumber resting on a shelf built into the side wall of the canyon extends 190 feet on a grade of 1 in 8 to a point beyond the toe of the dam, and discharges the surplus water over and against a rock cliff below. (Pl. VIII, fig. 1.)

RESULTS SECURED.

The dam and the rest of the work were completed April 1, 1899. Twenty-three thousand cubic yards of rock, 810 cubic yards of cement concrete, 183 cubic yards of asphaltum concrete, 69,800 pounds of steel, and 50,500 feet, board measure, of lumber were used in the construction. The total cost was $50,200. The capacity of the reservoir was 3,845 acre-feet, which gives a cost of $15.65 per acre-foot. The area of the surface of the reservoir at 58 feet above the bottom of the tunnel was 225.4 acres.

The water in the reservoir was rising rapidly at the time of the completion of the dam, and within two weeks thereafter was discharging through the wasteway. About six weeks after this the valves were closed and the leakage was measured. This was found to be 2.7 cubic feet per second coming through innumerable small holes through the rock cliffs on each side of the dam. The company began drawing on the reservoir for its canal on July 5, 1899, using a flow of 50 cubic feet per second. During the winter of 1899–1900 but little snow fell in the mountains, and all the streams became low early the following spring. The company opened its reservoir gates on June 22 and supplied its customers with water for two months at a time when other canals were dry.

RAISING THE DAM.

In the summer of 1900 the dam was examined with a view to raising it 25 feet higher. It was found that the dry walls had settled about 1 foot, the steel plate being in good condition. A contract was let for raising the dam to 83 feet above the outlet tunnel. The plan followed lines similar to those of the original dam, except that the steel core wall was inclined downstream at an angle of 30° from the vertical, which was necessary to connect properly with the side walls of the canyon. The rock was removed from around the steel to a depth of 10 feet and the new steel was riveted as in the original dam and covered with hot asphaltum. The walls on the downstream side were built up to the full height of 25 feet and the steel core wall was anchored to them. The lateness of the season made it necessary to suspend work, close the valves, and begin to store water before the upstream side of the steel plate was properly protected. (Pl. VIII, fig. 2.) The reservoir was used in 1900 and 1901 without any protection to the steel plate. The cost of this improvement was $35,500.

The capacity of the reservoir was increased by this addition to 8,895 acre-feet, which provided 70 cubic feet per second of water for 60 days. The surface of the enlarged reservoir became 262 acres. In 1901 an estimate was made of the value of the crops produced with reservoir water, and the aggregate was found to be over $40,000, which figure will be materially increased when several hundred acres of young orchard, irrigated with water from this reservoir, come into full bearing.

SECOND ADDITION.

In the fall of 1902 the company decided to add another 17 feet to the height of the dam and bring it up to an even 100 feet above the outlet tunnel, as originally contemplated. An examination showed that that part of the steel core wall that had been left unprotected was in such condition as to necessitate taking it down and rebuilding it, and before work was commenced the steel fell, carrying part of the rear wall with it. The rivets were cut, the plates removed and rebuilt, continuing the core at an angle of 45° from the vertical. On the downstream side of the steel core a rough, rubble masonry wall, 6 feet in thickness, laid in cement mortar, was built 5 inches from the steel core wall, and this space filled with hot asphaltum concrete mixed as in the original dam, and tamped into place. Next to the steel plate on the upstream side a layer of 4 inches of asphaltum concrete was laid. This was covered with lumber 4 inches thick. A facing of stone was laid over this 10 feet thick. At the ends of the steel plate trenches were cut into the rock and the asphaltum concrete widened out to 4 feet on each side next to the side walls. The top width of the dam was made 15 feet. The downstream slope remained at 2 to 1. The form and location of the wasteway were the same as in the original dam and extended beyond the toe of the dam.

The main and auxiliary valves were examined and found to be in good condition. Additional gearing and stems were added to bring the handwheels above the top of the dam and render them more easily operated. A lining of 4 inches of cement concrete was put into that part of the tunnel above the main valves; and the lower end was extended by cutting under the cliffs and discharging the water beyond the toe of the dam as enlarged. The work was not completed until the spring of 1904. On May 13 the reservoir was full of water. There was found to be no perceptible increase in leakage through the dam, and every part proved in operation to be all that was anticipated.

COST OF DAM.

The entire cost of the dam and reservoir from the date of the first surveys in 1894 until the completion of the third portion of the structure in 1904 is given in the following itemized statement. The item for sundry expenses includes a large number of individual expenditures such as measuring weirs, a building, repairs, etc., which have been grouped under this head:

Itemized statement of cost of East Canyon Dam, Utah.

Excavation of foundation, 940 cubic yards, at $2.30 per yard	$2,162
Portland-cement concrete, 1,520 cubic yards, at $8.50 per yard	12,920
Asphaltum concrete, 660 cubic yards, at $10 per yard	6,600
Steel plate in place, 164,200 pounds, at 7 cents per pound	11,494
Masonry laid in cement mortar, 2,280 cubic yards, at $6 per yard	13,680
Excavation of tunnel and valve chamber, 520 cubic yards, at $8 per yard	4,160
Lumber, 120,000 feet, at $30 per M feet	3,600
Valves, stems, pipes, and appurtenances	2,400
Rock derrick placed in wall, 28,000 cubic yards, at $1.24 per yard	34,720
Rock blasted down into dam, 68,600 cubic yards, at 25 cents per cubic yard	17,125
Land purchased	1,000
Roads and bridges around reservoir	1,500
Sundry expenses	8,000
Engineering, superintendence, and incidental expenditures	8,000
Total	127,361

The available capacity of the completed reservoir at the 100-foot level from the outlet tunnel and at the 145-foot level from bedrock is 13,800 acre-feet and its area 280 acres. Comparing the total cost with the available capacity, the cost per acre-foot is $9.23. The term "available capacity" is here used because in operation it has been found that the computed capacity of the reservoir has been considerably increased by water stored in underground reservoirs, which as the reservoir is drawn down returns to the main reservoir and in this way not only compensates for the loss due to evaporation, but provides about 6 per cent in addition.

In 1904 a continuous stream of 115 cubic feet per second was drawn from the reservoir for 62 days. The water flows through the channel of East Canyon Creek, mingling with the natural flow to the junction of Weber River, thence down Weber River to the company's headgate, where it is diverted into the canal, now enlarged to 200 cubic feet per second capacity.

BENEFICIAL EFFECTS OF ENTERPRISE.

From a financial point of view the enterprise has been more successful than the most sanguine of its friends anticipated. A careful estimate of the crops produced by reservoir water in the year 1904 shows their value to be over $75,000, or more than 58 per cent of the cost of the entire storage works. Moreover, the value of the land under this canal has increased on an average 100 per cent. Many hundreds of acres of orchard have been planted that are beginning to bear fruit, all made possible by the construction of this reservoir. A water right in this canal and reservoir is regarded as one of the best in the State.

MILNER DAM, IDAHO.

This dam, on the Snake River in Idaho, is a good example of the loose-rock and earth-fill type. The data herein given is taken largely from Schuyler's work on reservoirs.[1] This structure consists of three dams, closing the main deep channel and two high-water channels of the river. Figure 27 gives a plan and section of these dams, and figure 28 gives a general view from the downstream side. The general plan of all these dams was practically the same, but in constructing the main-channel dam the work was rendered more difficult owing to the necessity of handling the low-water flow of the river. The south and middle dams were constructed first, and, being located in channels which were dry except at periods of high water, their construction was comparatively easy.

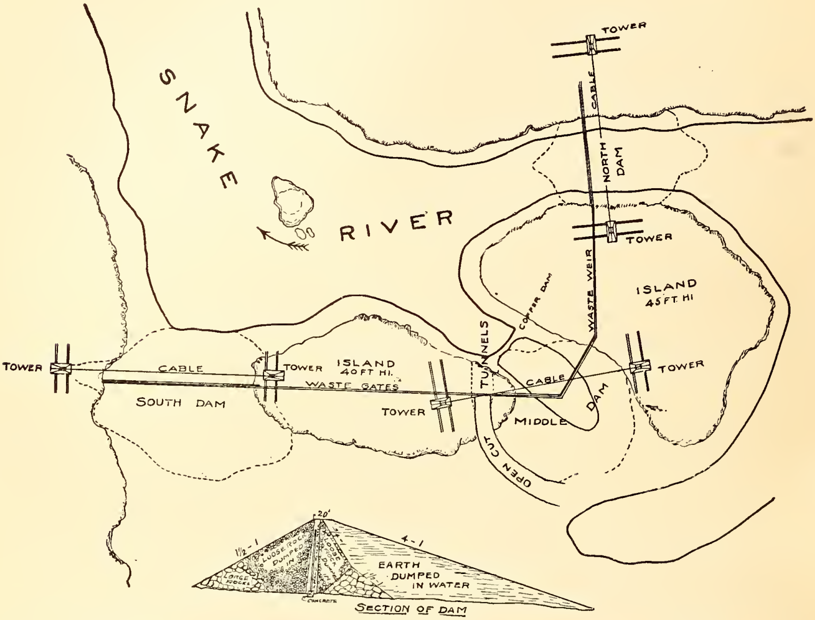

FIG. 27.—Plan and section of Milner Dam, Twin Falls project, Snake River, Idaho.

The building of these two dams will be first considered. The rock-fill portion was constructed with slopes of 1½ to 1 on the lower side and ¾ to 1 on the upper side. The entire surface beneath the rock

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[1] J. D. Schuyler. Reservoirs for Irrigation, Water Power, and Domestic Water Supply. New York and London, 1908, 2. ed., pp. 68–74, 125–127.

fill was first stripped of earth and loose material before any rock from the main quarries or the canal excavation was dumped into place. A trench 5 feet deep and 5 feet wide was then cut into the solid rock, the center line of which was directly under the center line of the crest of the rock-fill portion of the dam. This trench was extended up along the side walls of the canyon. A concrete wall 3 by 3 feet was built in the bottom of this trench, and a vertical, double-lap, pine plank fence having its bottom embedded in the concrete reached to the estimated level of the high-water mark of the reservoir after completion.

About 2 feet of concrete was placed in the trench before starting to build the wooden fence, and after the lower section of the latter was in position the concrete was built up another foot on each side of it. In placing the fence, vertical 3 by 6 inch studding were erected every 2 feet. These studding were of Oregon fir, of irregular lengths, and were lapped 2½ feet in splicing the joints as the fence was built up. Planking 2 by 12 inches by 12 feet, and longer, surfaced on one side and two edges, were closely spiked against these studding in two layers, making a total thickness of 4 inches. The second layer was so laid as to break joints, in all directions, with the first. Each plank in the first layer was nailed to each studding with two or more 40-penny spikes. The outer layer was spiked in the same manner with 60-penny spikes. The fence was kept about 5 feet higher than the stonework on either side, and great care was taken to maintain the horizontal and vertical alignment. The rock for the first 5 feet

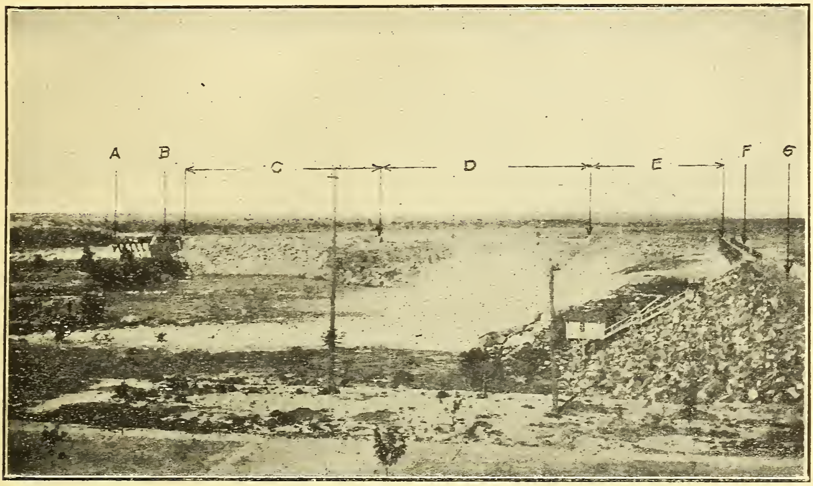

Fig. 28.—General view of Milner Dam, Snake River, Idaho: A, Control or wastegates on canal; B, Headgates, North Side Canal; C, North dam, length 340 feet on top; D, Spillway, concrete apron; E, Middle dam, length 335 feet on top; F, Regulating gates (99); G, South dam, length 560 feet on top. Total length of structure 2,100 feet.

on each side of the fence was laid by hand, care being taken to chink up the holes, fill the voids as closely as possible, and support the fence and keep it in line. The toe walls consisted of large rock, none of which was to weigh less than 1,000 pounds, and 50 per cent of which were to weigh 3,000 pounds and upward. These rocks were swung into place by derricks, and were so placed that the outer slopes of the toe walls were about 1½ to 1. The portion of the embankment between the toe walls and the core wall was made of rock taken from the canals, dumped in loosely from cableways, and spread roughly in layers of about 2 feet. The main portion of the loose-rock fill had a slope of ¾ to 1 on the upstream, and 1½ to 1 on the downstream side. Its upstream face was carefully laid by hand, making a dry wall 20 feet thick where it rested upon the toe wall, reducing to 10 feet at the top. Care was taken to make level beds and courses and fill all voids with spawls of rock.

FIG. 29.—Gates in Milner Dam, Snake River, Idaho. At times of high water these gates are raised to regulate flow in canals.

Before building the north or main-channel dam it was planned to cut a tunnel through the point of the south island of sufficient size to carry the low-water flow during construction. This tunnel consisted of eight sections, each 5 feet wide and 9 feet high. The flow of water was controlled by heavy cast-steel gates, raised by geared stands. (Figs. 29, 30.) Quoting from Schuyler's work, already referred to:

> An earth embankment or cofferdam was placed across the channel approaching the head of the tunnel to keep out water during its construction. At the same time rock in large blocks was deposited in the river channel, forming

two lines of embankment at the upstream and downstream toes of the rock fill, leaving a space between wide enough to permit the sinking of 24 feet by 12 feet timber cribs, with the upper faces on the longitudinal center of the rock-fill crest. The water found its way through and over these parallel levees of rock, which were built up until the water level was 13 feet higher above than below. By this time the tunnel was completed, the cofferdam was blown up by dynamite, and as much of the river turned through the tunnel as would go. About 4,000 second-feet found exit that way, and 1,000 second-feet passed through the loose rock of the channel dam. With the aid of divers the timber cribs were sunk on the center line of the rock fill, and a double thickness of sheet piling was spiked to the upper face of the cribs, which were loaded with stone. This piling was fitted to the bedrock bottom as carefully as possible, and the joints made tight by means of concrete in bags placed against the upper footing of the sheet piles. This work was done in a maximum depth of 40 feet of water, and finally all the water was forced through the tunnel. The remainder of the work above the water line was similar in plan to the other two dams, the wooden fence being built as a continuation of the sheet piling.

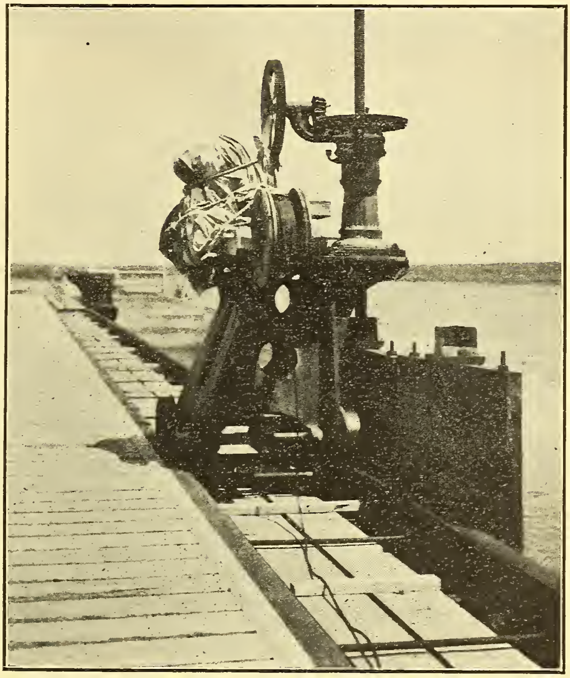

Fig. 30.—Milner Dam, showing lifting apparatus operated by electric motor.

The earth filling on the upstream face of these dams was placed by sluicing the materials through flumes to the point of discharge on the dam. The material available for this purpose was a very finely divided volcanic ash, which was found quite difficult to saturate in bulk. However, by the use of water pumped from the river, the material, dumped into a box at the borrow pit by slip-and-wheel scrapers and dump wagons, was saturated and sluiced through a flume and deposited in that form in the embankment. The following is a further quotation from Schuyler:

> The earth had to be obtained at a distance of 2,000 to 8,000 feet from the dam. * * * The volume of water discharged by single 4-inch centrifugal pumps was about 1.5 second-feet. The flumes were about 12 inches square, open at top. * * * All of the earth for the south dam and a large part of

that for the middle dam, except for the base, was hauled by cars and electric locomotives from borrow pits a mile or more away on the south side of the river. It was loaded into the cars either by teams through traps or by an electric shovel and dumped at the nearest end of the dam at such an elevation that the water would carry it on a grade to the further end. The grade naturally assumed by the earth thus sluiced was from 2 to 4 per cent. The liquid mud freely entered the voids of the rock fill and filled them solidly as far as the center core wall of wood. As it rose in height some slight leakage would show below for a time, but the joints in the wood quickly swelled and filled with mud and became entirely tight. The earth was always 20 feet or more below the top of the rock fill, and the work progressed at such a moderate rate that the embankments had ample time to settle and solidify. The earth packed so readily that in four days' time after sluicing was suspended a team could be driven over the embankment without sinking in, although while sluicing was in progress a pole could be pushed down into the mud to a depth of 10 feet or more, particularly at the extreme end, where the water stood longest in the pool.

Very little surface drainage was required to get rid of the surplus water. It seemed to be absorbed and disappear without showing up either above or below the dam. The earth came to the dam in a pulverized, dusty condition, and the water was sprayed upon it and at once saturated it to the softest of mud. About 80 per cent of the earth in the south and middle dams was sluiced in place, and 20 per cent put in by teams at the outer slope. The dry portion constantly absorbed moisture from the adjacent mass of mud, and thus became equally hard and solid.

The hydraulic filling of the north or channel dam was principally delivered from the north side of the river through a flume into the upper end of which a receiving box was placed, into which the earth was dumped from wagons through a trap, where the pumped water sluiced it down to the dam.

The earth was loaded into the wagon by means of a traveling excavator with belt conveyors that delivered a continuous stream of earth to the wagons traveling by its side until each received its load.

In this case the water used was about 1 second-foot, and the lower end of the flume discharged along the upper side of the wooden core wall, on top of the rock fill, first filling the voids in the rock and then extending upstream into deep water 20 to 30 feet in depth. On reaching the water it assumed a very flat slope under the water line of 6 or 7 to 1. When the fill had reached the top of the water by this process the slopes were drawn in to the regular 4 to 1 slope.

In the general view of this dam (fig. 28, p. 53) already referred to, the headgate of the North Side Twin Falls Canal is shown at B. Similar headgates of the South Side Twin Falls Canal are shown more in detail in figure 31.

The contract prices for this work were as follows: Dry embankment, 27.5 cents per cubic yard; earth embankment, placed by sluicing, 37.5 cents per cubic yard. These prices were necessarily high on account of the remoteness of the locality, the high cost of fuel, labor, supplies, and materials.

The weak feature of this dam as built is the wooden core wall. The life of the upper portion of this wall, which is subject to wet and dry conditions, can not be expected to be more than 10 or 12 years. The designers evidently intended the wooden core wall as a temporary expedient to insure water-tightness until the earthen embankment in front and the material sluiced into the open spaces in the rock had been sufficiently consolidated to insure imperviousness.

MINIDOKA DAM, IDAHO.

[U. S. Reclamation Service.]

This dam was constructed by the United States Reclamation Service at the head of the Minidoka Rapids on Snake River about 6½ miles from Minidoka, Idaho. The work at times was rendered very dangerous and quite difficult by the high-water stage of the Snake River. The flood flow of this river June 20, 1906, near Minidoka gave a total maximum discharge of 24,300 cubic feet per second. The dam complete consists of a loose rock fill 664 feet long, with a concrete core wall faced on the upstream side with a heavy earth embankment; a concrete spillway, headgates, and forebay canal. (Fig. 32.) The length of the entire structure is 4,412 feet. Construction was begun in December, 1904, but owing to various delays the work did not get fairly under headway before January, 1905.

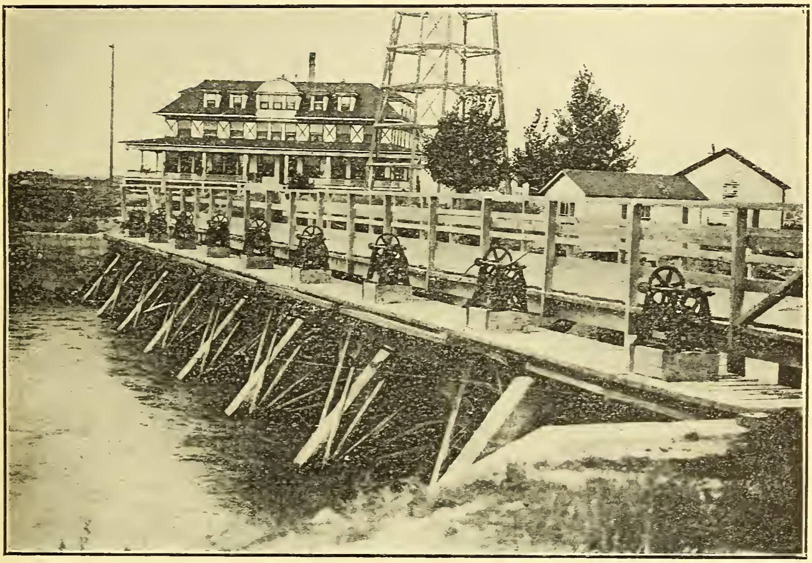

FIG. 31.—Headgates, Twin Falls Canal system, South Side, at Milner, Idaho.

The main dam is of the loose-rock-fill type, with a concrete core back filled on the upstream slope with earth and gravel. This slope has a heavy gravel face protected by cyclopean riprap (fig. 33).

Before constructing the loose-rock fill a channel for diverting the flow of the river was excavated through the rock point at the north end of the dam. This channel was closed by a concrete dam (fig. 34) containing five 8 by 12 foot coffin sluice gates (fig. 35). A concrete

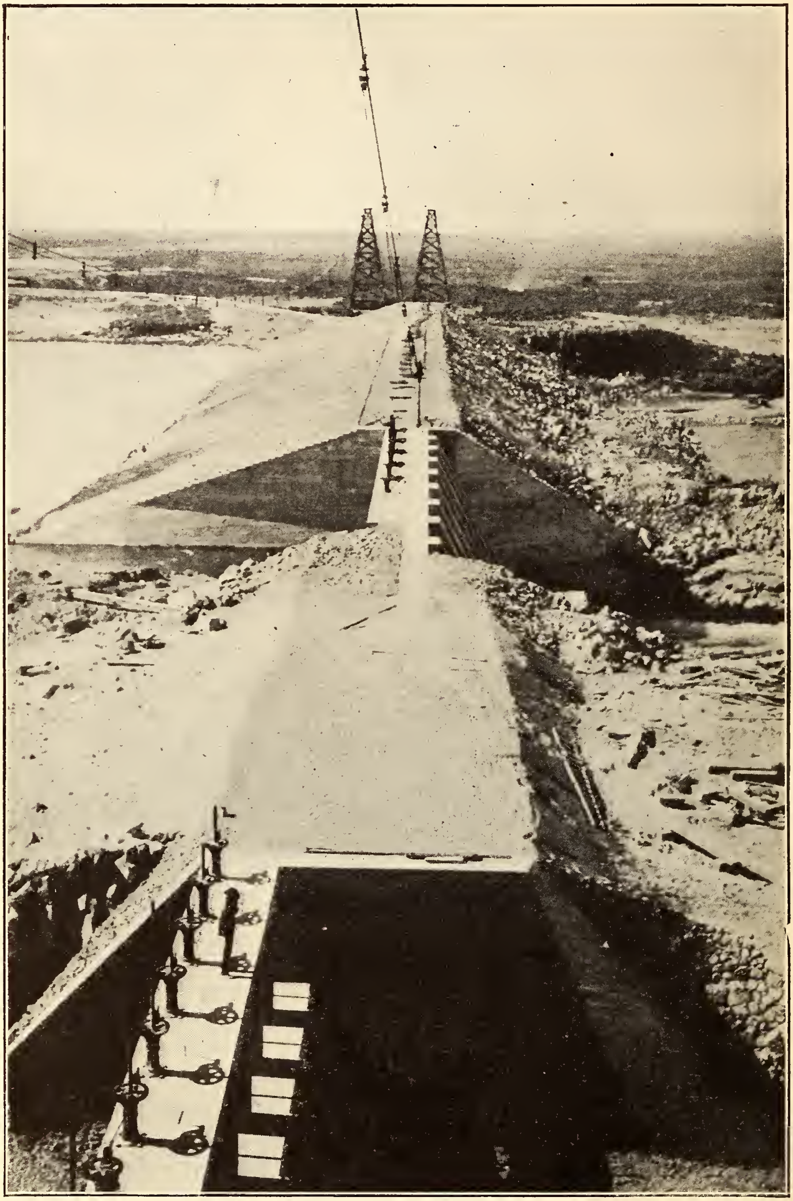

FIG. 32.—Minidoka Dam, Snake River, Idaho (U. S. Reclamation Service).

spillway (fig. 36), 2,385 feet long, was built at the south end of the dam, following the highest ridges of rock. The excavation for the foundation of the loose-rock dam was practically all wet and required constant pumping. Very little rock was taken out, nearly all the material being that which had washed into the deep channel during the construction of the cofferdam. This channel, though narrow,

FIG. 33.—Riprapped slope, Minidoka Dam, Snake River, Idaho.

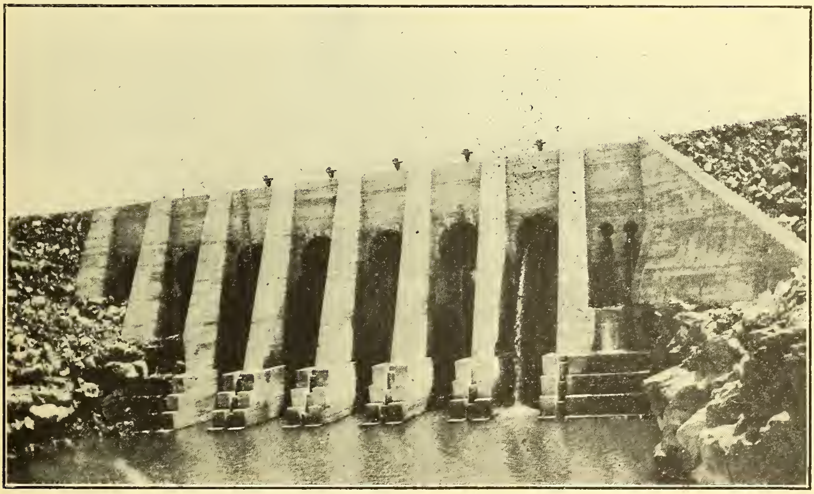

FIG. 34.—Concrete dam in diversion channel, Minidoka project (U. S. Reclamation Service), Idaho.

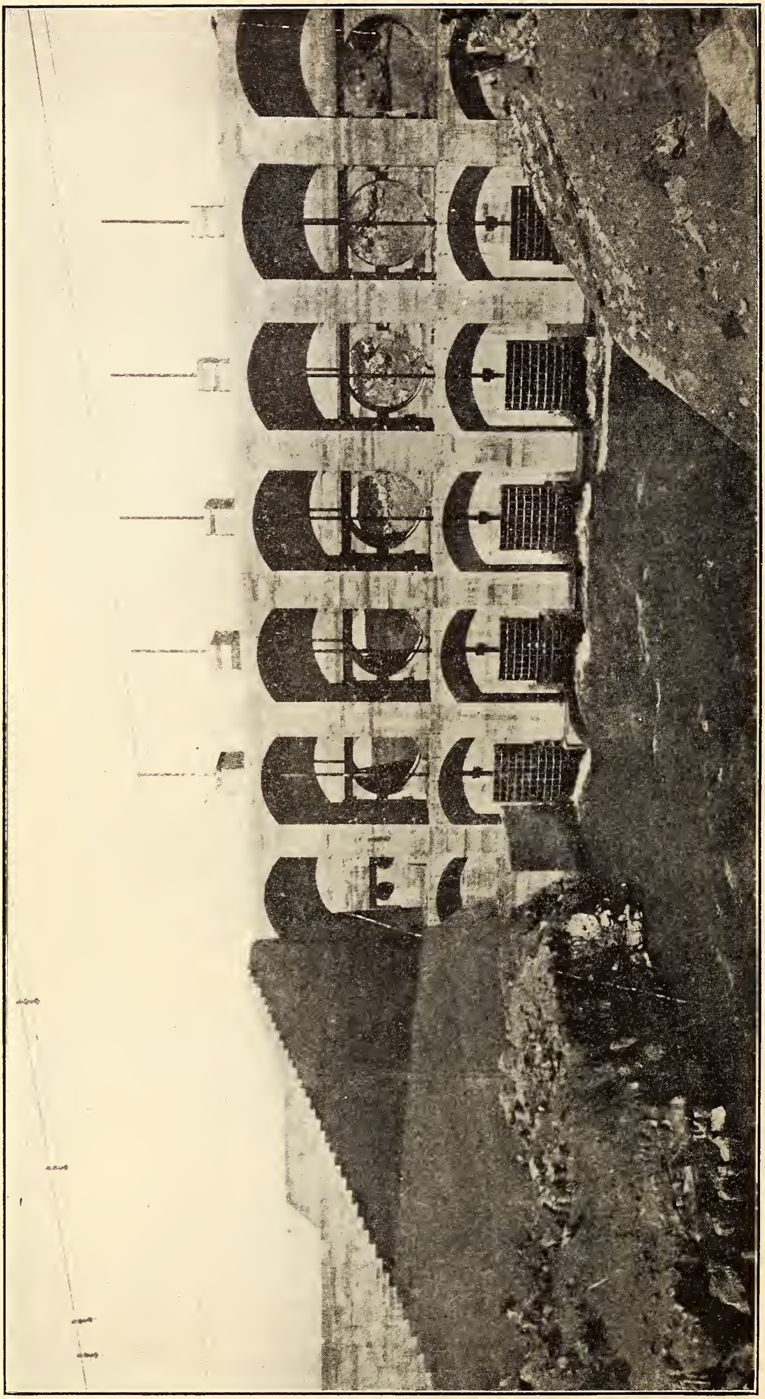

FIG. 35.—Upstream side, concrete dam in diversion channel, Minidoka project (U. S. Reclamation Service).

was 25 feet deep, and two rows of sheet piling had to be driven full depth ahead of the excavation. A break in the cofferdam, when the excavation was practically complete, caused considerable delay and additional expense. Figure 37 shows the method and sequence of the construction of the main loose-rock dam. The portion in the deep channel marked (1) was constructed first, subscripts showing the sequence of construction in that part. The water meanwhile was diverted through the portion marked (2), which was next constructed, forcing the water back through the diverting channel. The embankments (1), (1_2), (1_3), (2_1), and (2_2) when finished formed a cofferdam for the construction of the core wall, after which the upper filling was continued across the whole channel. Practically all the rock excavated from the diversion channel was placed in the dam. The average haul for this portion of the rock, which was a little over two-thirds of the total amount, was 450 feet, including haul by cableways. The remainder of the rock was obtained from the upper end of the canal and the haul averaged 900 feet. About one-eighth of the rock could be reached directly by the cableway and required no hauling on cars. The cars used were simply trucks on which the skips were hauled from the derrick to the cableway, one horse being used to haul three cars. Two cableways were constructed, each 1,300 feet long and consisting of a patent lock wire 2 inches in diameter.

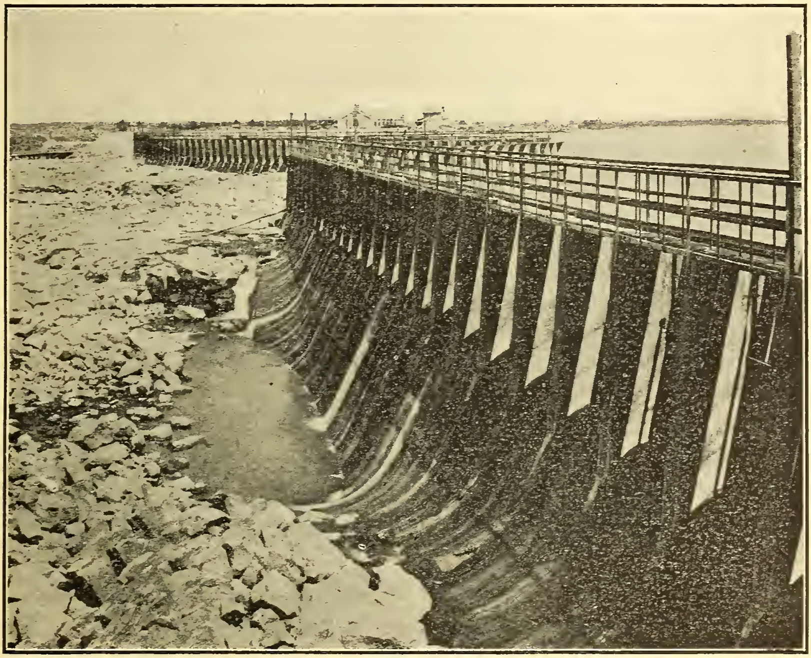

FIG. 36.—Spillway, Minidoka Dam, Idaho (U. S. Reclamation Service).

Each cable was supported by two movable wooden towers, 81 feet high. These towers were mounted on trucks to facilitate their being moved to any line parallel to the axis of the dam. The span of the cableway between the towers was 1,150 feet. The necessary carriages and hauling and hoisting lines for the lifting and conveying of the material were supported from these cables. The hoisting lines were operated by two 65-horsepower triple-friction drum, reversible, link-motion hoisting engines. Steam was supplied by two 80-horsepower boilers, one boiler and engine being located on the base of each head tower. The arrangement of the machinery was such that the load could be dumped at any point by the engineman, the safe working load being 7 tons. The rock was carried in heavy steel skips, each having a capacity of 3 cubic yards. This method of placing rock

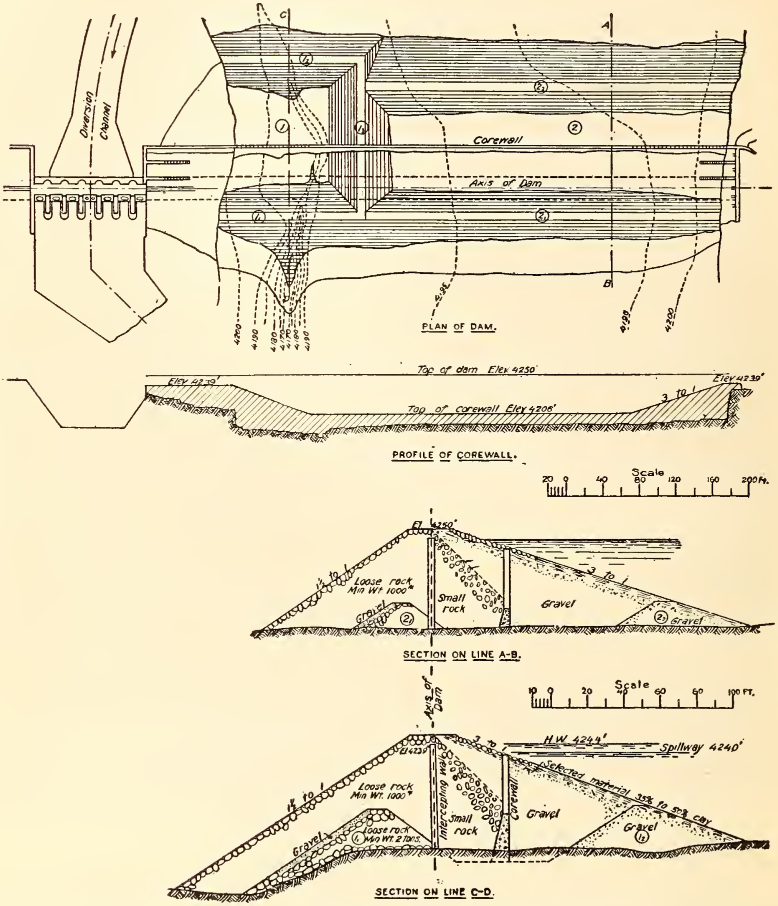

Fig. 37.—Plan and sections of Minidoka Dam, Idaho, showing sequence of construction (U. S. Reclamation Service).

while fairly economical, was open to some objections, chief of which was its limited capacity. When taking rock from the canal it required five minutes for a skip, running at full speed, to make the trip to the center of the dam and back. This gave a maximum capacity of 120 trips per 10-hour day. The average number was only 100 trips, which, at $1\frac{1}{2}$ cubic yards per skip (measured in excavation), gives 150 cubic yards per day as the average capacity of each cableway. The rock was dropped from a height of 10 to 50 feet and made a very compact fill. While putting in the base of the dam both cableways were used, but as the section became narrower only one cableway could be used. When the rock was within 15 feet of the top it became necessary to raise the embankment rapidly on account of high water. For this purpose the capacity of the cableway was insufficient to keep ahead of the water. It was fully expected that the river would discharge over the spillway during the high water, but it rose only to within 3.2 feet of the crest of the weir. Before this stage was reached the rock fill had been raised to its maximum height—52 feet—which is 13.2 feet above the highest level reached by the river. At this level the water passed freely through the rock fill, the leakage being estimated at 1,000 cubic feet per second, which was evenly discharged throughout the length of the dam.

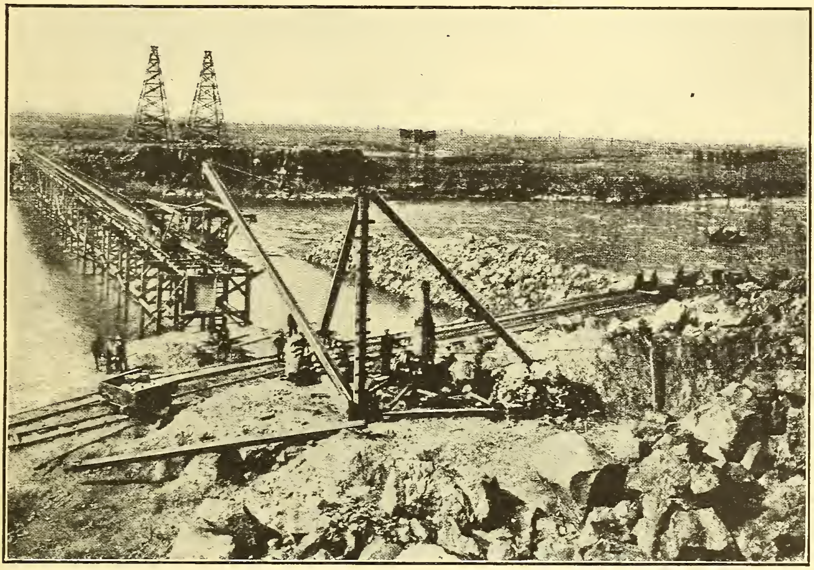

FIG. 38.—Showing derrick handling skips, and cableways in action; also showing double trestle from which earth was dumped in the back-filling, Minidoka project, Idaho (U. S. Reclamation Service).

For the purpose of placing the earth-gravel back filling in the dam a double trestle (fig. 38) was built across the river and tracks laid to the borrow pits, 1,200 to 1,800 feet from the nearest point on the dam. An orange-peel excavator with a 1-yard dipper was installed for loading the cars at the borrow pit. The excavator was supplemented by hand shoveling and by traps and teams in loading the cars. These cars were of the side-dump type and had a capacity of 3 yards, one team of horses hauling three cars. A steam hoist was used for pulling the loaded cars up a slight incline to the approach of the bridge and for pulling empties off the bridge. The elevation of the bridge was about 20 feet below the top of the dam. When it could be used no longer, a track was laid on top of the rock fill and the gravel and earth were dumped from the cars into the water. At first a comparatively large percentage of this material was carried into the rock fill, but the voids were soon filled and the water completely shut off. The entire loose-rock fill was made watertight under those conditions and very little settlement resulted. This latter condition is due to the fact that earth deposited under water is formed into a most compact embankment, which in most cases is impervious to the passage of water.

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